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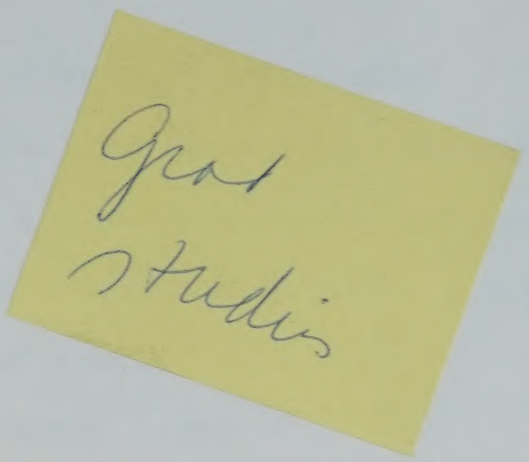
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THE CONTEMPORARY AND SUBFOSSIL MOSS ASSEMBLAGES OF A HIGH ARCTIC UPLAND SOUTHERN PIPER PASS NORTHERN ELLESMERE ISLAND, N.W.T.

BY

CATHERINE LaFARGE-ENGLAND

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN

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IN

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DEPARTMENT OF BOTANY

EDMONTON, ALBERTA

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The Contemporary and Subfossil Moss Assemblages of a High Arctic Upland, Southern Piper Pass, Northern Ellesmere Island, N.W.T. submitted by Catherine LaFarge-England in partial fulfillment of the requirements for the degree of Masters of Science in Paleoecology.

[redacted]

Date: April 11th 1988

To John, Jennifer, and Margaret

ABSTRACT

A quantitative analysis of contemporary moss assemblages is presented for a fault block, at the southern end of Piper Pass ($82^{o}12'N$, $68^{o}31'W$), Northern Ellesmere Island, N.W.T. Twenty eight stands are analyzed using a two way indicator species analysis, resulting in seven major species groups and five major stand groups. Physical parameters are correlated with the stand data and these show percent soil moisture and slope as the most important factors influencing moss assemblage distribution. Detrended correspondence analysis confirms these stand relationships. Distribution patterns of the species groups throughout the stand groups are analyzed by means of a percent frequency diagram. Five new species are reported as disjunct to continental North America. The quantified contemporary moss assemblages are used to interpret the subfossil moss assemblages found at the site.

The development of four autochthonous peats, 2 - 4 meters in thickness, on the north-facing slope of the fault block are analyzed. Ice-wedge polygons have developed on the lower 2/3 of the slope. A quantified macrofossil analysis by % volume was done on the four deposits, resulting in 28 species of mosses. Four of these are new to the North American fossil record. Results show analogous, modern day assemblages. The chronology indicates initial peat formation at 6315 BP (S-2449). A cross check on the dating by the accelerator mass spectrometer gave a minimal date on individual moss fragments of 6410

BP (TO-284). The youngest sample dated was 760 BP (S-2449). The dominant peat forming mosses were Philonotis fontana, Tomenthypnum nitens, Aulacomnium acuminatum, A. palustre, Hylocomium splendens, and Tortula ruralis. Conclusions from the subfossil analysis show that a diverse moss flora was present on northern Ellesmere Island during the Holocene. Variations in the assemblages within the profiles indicate changes in the hydrology of the slope and patterns of organic deposition rather than reflecting macroclimatic changes. However, rates of deposition were the most rapid between 5165 (S-2444) and 4720 BP (S-2443), which correlates with the period of greatest driftwood abundance (6000 - 4200 BP), indicating greatest summer warmth during the Holocene.

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I am indebted to the enthusiasm, encouragement, and constancy of John who has made this entire project possible: from the logistic support of the research in the high arctic, to editing the subfossil chapter, to the mothering of our children in my absence. The special gift of the arctic, I will never forget.

TABLE OF CONTENTS

CHAPTER PAGE

I. THE CONTEMPORARY AND HOLOCENE MOSS ASSEMBLAGES OF SOUTHRN PIPER PASS, NORTHERN ELLESMERE ISLAND, N.W.T., CANADA 1

Bibliography 7

II. THE CONTEMPORARY MOSS ASSEMBLAGES OF A HIGH ARCTIC UPLAND, SOUTHERN PIPER PASS, NORTHERN ELLESMERE ISLAND, N.W.T., CANADA 9

Bibliography 53

III. HOLOCENE BRYOPHYTE ASSEMBLAGES IN 2 - 4 METRE SLOPE DEPOSITS OF A HIGH ARCTIC UPLAND, SOUTHERN PIPER PASS, NORTHERN ELLESMERE ISLAND, 82^{0}N 63

Bibliography 120

IV. SUMMARY 130

Bibliography 134

APPENDIX 1 136

LIST OF FIGURES

Figure	Description	Page
I.1	Map of northern Ellesmere Island with study area indicated.	4
I.2	Map showing limits of last glaciation over the Hazen Plateau.	5
II.1	Known floristics in the high arctic	32
II.2	Map showing study area.	32
II.3	Air photo of the fault block.	33
II.4	A profile of late lying snowbank slope.	34
II.5	Stand C 12	35
II.6	Stand C 6	35
II.7	Stand C 21b	35
II.8	Stand C 23	35
II.9	DCA ordination of the stands	36
II.10	DCA ordination of stand groups	36
II.11	TWINSPAN dendrogram of stand groups	37
II.12	Percent soil moisture classes for each stand	38
II.13	Slope classes for each stand	38
II.14	Percent organic content classes for each stand	38

Figure	Description	Page
II.15	Sodium values from soil samples of the stands ..	38
II.16	Species diversity from quadrat samples within the stands.	38
II.17	Percent frequency diagram	39
II.18	Prominence values for Hypnum revolutum throughout the stands	40
II.19	Prominence values for Tortula ruralis throughout the stands	40
II.20	Prominence values for Timmia austriaca throughout the stands	40
II.21	Prominence values for Philonotis fontana throughout the stands	40
II.22	Prominence values for Drepanocladus brevifolius throughout the stands	40
II.23	A diagramatic representation of the C 15 transect slope.	41
III.1	Locality map of study area	101
III.2	Delimitation of the ice margin on the Hazen Plateau during the last glaciation	102
III.3	Air photo showing the sites of the sampled peat sections	103

Figure	Description	Page
III.4	Macrofossil size range	104
III.5	Panorama of peat forming slope	105
III.6	Polygon development on peat forming slope	106
III.7	Horizontal fissure development	107
III.8a	General photo of PT 3	108
III.8b	Detail of PT 3 section	108
III.9	Macrofossil diagram of PT 3	109
III.10	Rate of deposition of the four peat deposits	110
III.11a	General view of PT 4	111
III.11b	Detail of PT 4	111
III.12	Macrofossil diagram of PT 4	112
III.13a	General view of PT 1	113
III.13b	Detail of PT 1	113
III.14	Macrofossil diagram of PT 1	114
III.15a	General view of PT 2	115
III.15b	Detail of PT 2	115
III.16	Macrofossil diagram of PT 2	116
III.17a	Ordination of the contemporary stands	117
III.17b	Percent soil moisture classes superimposed on the ordinated stands	117

LIST OF TABLES

Table	Description	Page
I.I	Northern Ellesmere terrestrial organic dates	6
II.I	Species richness of mosses at various high arctic localities	42
II.II	Correlation coefficients of physical parameters ...	43
II.III	TWINSPAN classification of stand groups and species groups. A complete list of species for southern Piper Pass is included.	44
III.I	A list of the 13 dominant subfossil mosses with their distributions through the contemporary stands. Moisture preferences are indicated	118
III.II	A list of radiocarbon dates from the southern Piper Pass peats	119

CHAPTER I

The Contemporary and Holocene Moss Assemblages of Southern Piper Pass, Northern Ellesmere Island, N.W.T., Canada

by

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INTRODUCTION

Northeastern Ellesmere Island, N.W.T. has been proposed as a biological refugia based on botanical, entomological, and glacial geomorphological data (Fig.I.1). The botanical evidence has stressed the presence of endemics, disjuncts, and high species richness (Brassard 1971a, 1971b, 1971c; Schuster et al. 1959; Soper and Powell 1985,; England et al. 1981; Gould 1985). The entomological work has stressed the presence of numerous flightless insects (Leech 1966). As well, geomorphological evidence delineates a restricted ice margin during the last glaciation that left ice-free areas from at least 8000 to 32,000 BP (England and Bradley 1978, Fig.I.2). However to date, refugial localities have not been designated based on in situ vegetation history during and since the last glaciation.

During the 1981 field season a prominent fault block, located along the southern margin of the United States Range, was noted to support a lush and diverse vegetation compared to the rest of the Lake Hazen Basin. Subsequently, during a three day reconnaissance of this fault block, 80 species of mosses were collected. This preliminary survey emphasized the potential species richness for the locality, which is restricted to an upland site. Lake Hazen (114 spp.) and Tanquary Fiord (125 spp.) have the highest species richness determined for the Central Region of northeastern Ellesmere Island (Brassard 1971a, 1971b, 1976, 1979).

The fault block is also mantled by thick peat deposits for this latitude. Zoltai and Pollett (1974) described the high arctic as having basin and seepage fens, which contain shallow peat deposits. Within the basin fens, they stated that peat development is minimal, with the mean

thickness 50 cm. Seepage fens, which develop on slopes and have a continuous moisture supply throughout the growing season, usually have less than 20 cm of peat. During the 1982 field season, an approximately four meter thick, seepage fen peat was discovered on the fault block. Previous collections from peat deposits on the fault block have yielded radiocarbon dates, ranging from >33,000 to 2800 BP (Tab.I.I). From the point of view of both the contemporary and subfossil vegetation, it is apparent that the fault block is of particular interest.

OBJECTIVES

The principal objectives of the research are: 1) to quantitatively analyze the contemporary moss assemblages and determine the physical parameters controlling the distribution of the mosses; 2) to quantitatively analyze the past bryophyte assemblages and relate these to the contemporary bryophyte assemblages of the fault block; 3) to analyze individual species through the development of a deposit and to interpret the changes in terms of microhabitat modifications; 4) to analyze the development of the bryophyte assemblages through time; 5) to interpret the paleoecological implications of the data and how they correspond to previous data from the high arctic.

The subsequent chapters will emphasize the contemporary and the subfossil moss assemblages. By understanding the distribution of the contemporary moss flora on the fault block, an interpretation of the subfossil moss assemblages is possible. A detailed analysis of 25 stands of the contemporary vegetation and four autochthonous peats are presented. Physical and chemical data from the contemporary assemblages are used to analyze the subfossil moss assemblages. An interpretation of the late Quaternary environment on northern Ellesmere Island is given based on the in situ deposits.

Figure I.1. A map of northern Ellesmere Island. The circled area indicates the study area.

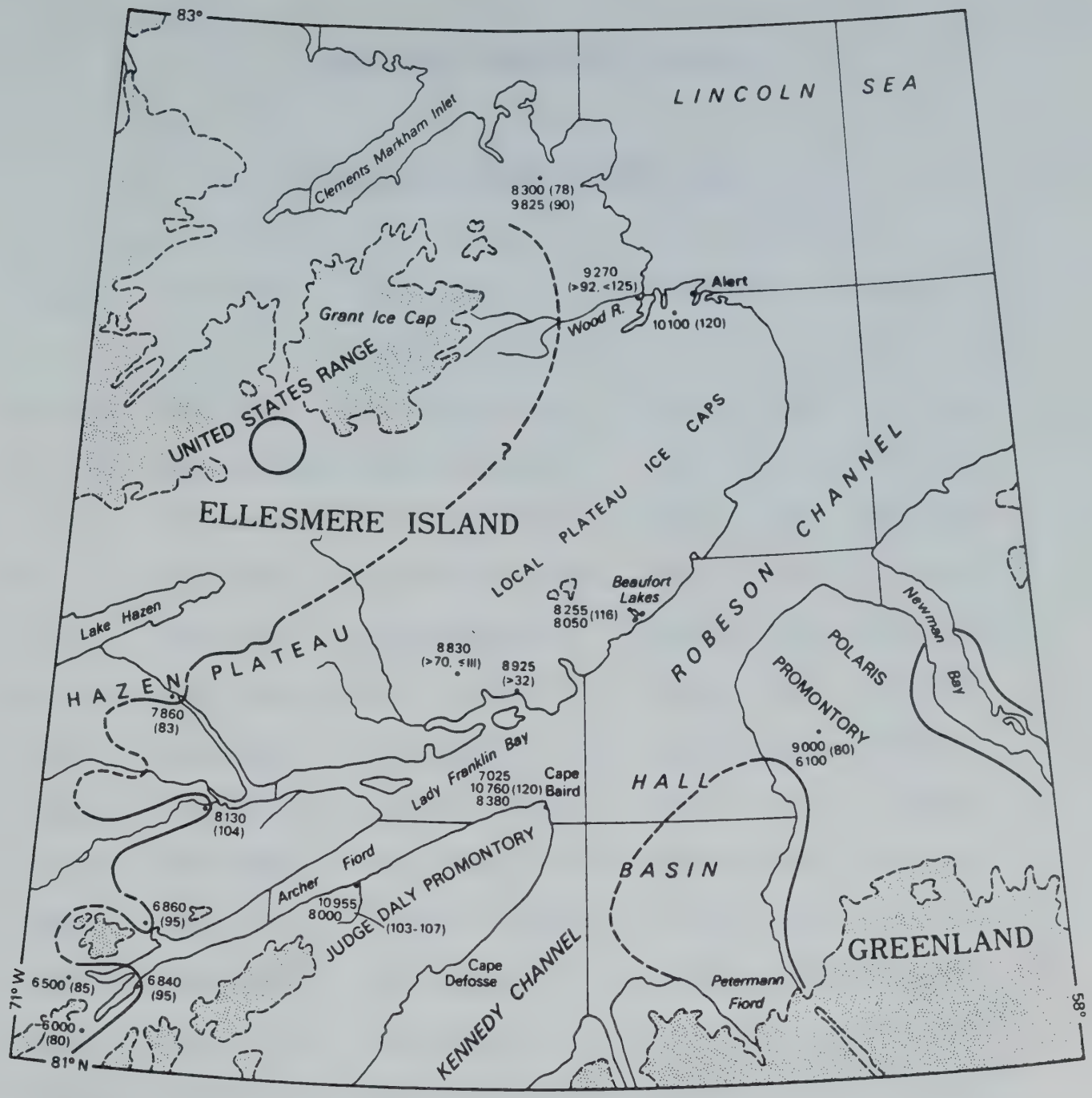

Figure I.2. A map showing the restricted ice margin during the maximum advance of the last glaciation on northern Ellesmere Island. (Modified from England 1983). The circled area shows the study area.

QUATERNARY TERRESTRIAL ORGANICS

OF

NORTHERN ELLESMERE ISLAND, N.W.T.

sample #	locality	lat./long.	^{14}C dates	lab #
F1 1-81	Piper Pass	81 11 N,68 30 W	2870 +/- 245	S-2118
EG 1-81	Hazen Plateau	82 06 N,66 04 W	2805 +/- 70	S-2120
Gould	Lake Hazen	81 50 N,71 47 W	3260 +/- 70	GSC-3540
F1	Piper Pass	82 15 N,68 20 W	4755 +/- 135	S-2230
Gould	Lake Hazen	81 50 N,71 47 W	4980 +/- 70	GSC-3451
TGS No.	Piper Pass	82 39 N,68 05 W	7070 +/- 115	S-2504
F1 s9	Piper Pass	82 11 N,68 30 W	7185 +/- 260	S-2661
Lemmen	Disraeli Fi.	82 36 N,72 45 W	7730 +/- 70	TO-493
TGS No.	Piper Pass	82 37 N,68 28 W	8415 +/- 135	S-2501
Lemmen	McClintock	82 38 N,75 38 W	14,730 +/-120	TO-498
Lemmen	McClintock	82 38 N,75 37 W	15,710 +/- 180	TO-497
Lemmen	Marvin Pen.	83 00 N,75 39 W	23,340 +/- 430	TO-489
Lemmen	Disraeli Fi.	82 36 N,72 54 W	31,360 +/- 400	TO-492
F1 4-81	Piper Pass	82 10 N,68 25 W	> 33,000	S-2119

Table I.1. Radiocarbon dates on terrestrial organics from northern Ellesmere Island.

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CHAPTER II

The Contemporary Moss Assemblages of a High Arctic Upland, Northern Ellesmere Island, N.W.T., Canada[1]

by

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1 A version of this chapter has been accepted for publication. LaFarge-England,C. 1988. Canadian Journal of Botany.

INTRODUCTION

The composition of the high arctic moss flora has been studied mostly in the past 40 years (Fig.II.1, Tab.II.I). These data provide information on the distribution, taxonomy, and ecological preferences of arctic species. A few studies in the arctic have concentrated on descriptive ecology of contemporary moss assemblages (Brassard 1971a, Holmen 1953, 1960, Kuc 1969, 1973, Martensson 1956, Schuster et al. 1959, Steere 1947, 1978). Some studies have used quantitative ecological methods that included bryophytes (Bell and Bliss 1980, Bliss and Svoboda 1984, Bliss et al. 1984, Brossard et al. 1984, Gould 1985, Miller and Alpert 1984, Nimis 1985, Sheard and Geale 1983a, 1983b, Sohlberg and Bliss 1984, and Vitt and Pakarinen 1977). However, the majority of studies have emphasized the vascular plants, and have not included bryophyte species. Review articles, which discuss the state of arctic bryology, can be found in Brassard (1971a), Longton (1982), Schofield (1972), and Steere (1953, 1971, 1976, 1979). The highest priority of future arctic bryological research surmised from these papers is quantitative bryoecology.

Mosses are an important component of the high arctic ecosystem in terms of species richness, cover, and production (Vitt and Pakarinen 1977). Subtle variations in microtopography are reflected by changes in the bryophyte assemblages (Barrett 1979, Nimis 1985, Steere 1976). Slack (1982) discussed the concept of microhabitat and niche in relation to bryophytes and reviewed the important studies. The term "ecotope" was used as a broad concept of niche, including the physical and environmental factors as well as competitive factors in an intercommunity sense. The present study concentrates on the physical

and chemical factors influencing moss distribution. Twenty-eight standswere quantified. An indirect gradient analysis of the moss component of the stands is made: stands are ordinated, stand groups and species groups are described, correlations of chemical and physical parameters with the vegetation data are established. Mesotopographic variation is also assessed in relation to vegetation distribution. A direct gradient analysis of a transect through a late-lying, snowbank slope is presented. The distribution of moss species in relation to a slope and moisture is interpreted.

Objectives

The objectives of the present paper are to describe the moss component of southern Piper Pass, northern Ellesmere Island, specifically to 1) estimate total species richness 2) quantitatively determine the moss assemblages, 3) correlate the moss assemblages to physical and chemical gradients, 4) determine the distribution patterns of the extant moss taxa in terms of ecological preferences and tolerances, and 5) formulate a contemporary data base for the analysis of subfossil moss assemblages of the peat deposits within the study area.

STUDY AREA

The study area is located on a fault block at the southern end of Piper Pass, northern Ellesmere Island, Canada, between the Grant Land Mountains to the north and the Hazen Plateau to the south (Fig.II.2). The fault block at $82^{o}12'N$, $68^{o}31'W$, rises from the Hazen Plateau 457 m to a major tableland at 610 m and reaches a height of 915 m. It occurs along what has been termed the Lake Hazen Fault Zone (Christie 1964), indicating past tectonic activity. The terrain directly to the

north is characterized by deeply dissected valleys that drain the icefield of the Grant Land mountains. To the northeast, Piper Pass, a deep tectonic trench, separates the fault block from the United States Range to the east. Although there are no major river systems on the upland site, there are a number of seasonal streams and several shallow ponds.

The study area is a Permian sandstone fault block dissected by a diabase dyke (Trettin 1971). The dyke forms a major ridge running northeast-southwest through the fault block (Fig.II.3). The sandstone lithology is primarily a fine to medium grained sandstone (Mial 1979). Initial geologic mapping of this area has been done by Christie (1964), Mial (1978, 1979), and Trettin (1971).

Maxwell (1981) described five climatic regions in the Canadian Arctic Islands. The study area is classified within the Axel Heiberg and Ellesmere Island Highland subregion within the more general Northern Region (Maxwell 1981). The precipitation regime of this region is controlled by orographic position that would otherwise be constrained by the predominant polar desert macroclimate (Barry and Jackson 1969). Annual precipitation data from 1957-58, at Lake Hazen, 60 km southeast of the study area, was as low as 2.5 cm/year (Corbet 1967, Jackson 1959). However, studies done on the Gilman Glacier, 30 km to the west of the fault block, indicated that annual precipitation along the southern margin of the Grant Land Mountains is 13 cm/year (Hattersley-Smith 1960). Since the fault block lies between these two elevations (Lake Hazen and the Gilman Glacier), it is likely that its mean precipitation is between 2.5 and 13 cm/year. Bovis and Barry (1974) have classified this region climatically as a polar desert, with

annual water balance close to zero. Corbet (1967) estimated the average frost-free season for Lake Hazen at 55 days (1962-1966 data), although the total number of frost free days for a given season may be more.

Physiological adaptation of mosses to polar regions has shown that respiration can take place in some species at -4^{o}C (Smith 1984). Longton (1979), Oechel and Sveinbjornsson (1974), and Oechel et al. (1975) have discussed the physiological adaptations of mosses to polar desert environments.

Differences between air and surface temperatures are substantial in the high arctic (Courtin and Labine 1977, Powell 1961, Sohlberg and Bliss 1984), however microclimatic studies relative to the moss layer are limited. Longton (1972,1974) has completed studies of microclimatic effects on populations of on Polytrichum, Psilopilum, and Bryum argenteum. The microclimatic variation of relative humidity, solar radiation, temperature, wind, and snow depth influence the microhabitat of mosses in polar regions.

The study area is within the region of continuous permafrost with the active layer ranging from 20 - 100 cm in depth (England et al. 1981). Varying surficial sustrates, aspect, drainage, topography, and vegetation cover modify the active layer depth.

The glaciation level, the elevation above which permanent ice is encountered on surfaces with an adequate area for snow accumulation, is about 1100 m along the southern margin of the Grant Land Mountains (Miller et al. 1975). The glacial history of southern Piper Pass has been delineated by Brown (1985). He indicated that the Turnabout Glacier at one time extended 16 km beyond its present margin, wrapping around the southern edge of the fault block. At that time, it blocked

the drainage into southern Piper Pass from the Turnabout Glacier and the Divide Glacier creating a proglacial lake (Brown 1985, p.102). ^{14}C dates of allochthonous material from the lake sediments have suggested two possible ages for this lake, > 8000 BP being full glacial or < 8000 BP being post glacial. Brown (1985) concluded that the proglacial lake was synchronous with full glacial conditions.

The major bryofloristic research within the vicinity of the study area has been done by Brassard (1971a, 1971b, 1976, 1979), Schuster et al. (1959), Powell (1967), and England et al. (1981). Species lists, descriptive communities and bryogeographic regions have been published. The flora of northeastern Ellesmere is composed of 125 species of vascular plants (Soper and Powell 1985), a low estimate of 147 lichens, 47 hepatics (Powell 1967, Schuster et al. 1959) and 180 mosses (Brassard 1971b, 1976, 1979, and LaFarge-England (this paper). The species richness of the upland flora is partially a result of the diverse landscape (Figs.II.5-8).

METHODS

Three methods were used in the vegetation sampling. 1) Species cover was estimated in 28 stands, subjectively chosen for homogeneous vegetation and topography. In each stand, data was collected from ten, randomly placed, 25 x 25 cm quadrats . 2) A detailed transect of a ridge (80 m in elevation) (Fig.II.4) from the crest of the ridge to the seepage flats below included 16 stations at five meter intervals, each with three randomly placed 25 x 25 cm quadrats. 3) Non-quantitative methods of vegetation sampling, including collecting outside the designated quadrats within a stand and sampling specific microhabitats not found in any of the stands.

Percent cover was estimated to the nearest 1.0% for all vascular plants, lichens, and bryophytes within the quadrats. The quadrat data (methods one and two) were collected as per cent cover values, then modified to prominence values: $PV = C\sqrt{F}$; where PV = prominence value, C = mean per cent cover, and F = absolute mean frequency (Beals 1960). This modification weights species having low frequency.The subsequent analyses included only the bryophyte element of the communities.

Voucher specimens for each of the 117 taxa of mosses have been deposited in ALTA and CANM. Nomenclature for the taxa follows Ireland et al. (1980) with exceptions in Dicranum (Peterson 1979), Grimmiaceae (Cao and Vitt 1986), Pohlia (Shaw 1982), and Timmia (Brassard 1979, 1984).

Water and soil samples were collected, where possible, to determine a set of physical and chemical parameters for each stand. Analyses of these samples included surface water pH and specific conductivity; soil pH, % organic content, % moisture, available nutrients and texture. Slope and mesotopography data were additional physical factors noted.

Between June 18 and July 31 1983, surface water was collected from 12 of the 28 stands in acid-washed polyethylene bottles. Specific conductivity and pH were measured electronically in the lab, then stored frozen after the addition of two drops of HNO_3.

Soil samples from each stand (excepting stands C1, C3, C5, and C6) and from the 16 stations of C15 were collected. Each sample was taken to a depth of 2.5 centimeters using a 77 cm^3 sampler. This depth was chosen, because it is sufficient to contain rhizoidal penetration of the mosses (Schofield and Hebant 1984). Mineral adsorption is ectohydric opposed to endohydric, making the surface soil component

critical to mosses. The soil samples were stored at 2° to 3°C. Percent soil moisture was determined on a dry versus wet weight basis, with the dry temperature 105°C. Percent organic content was calculated by weight loss on ignition (LOI) at 550°C (McKeague 1976, Day et al. 1979). The ash was analyzed for available Ca, Mg, Na, and K by an inductively coupled argon plasma spectrophotometer using the ammonium acetate method at the Northern Forestry Research Center, Edmonton, Alberta. Approximately 20 grams wet weight of soil was used to determine pH from a soil slurry (McKeague 1976). Texture was determined by the hydrometer method (McKeague 1976, Anonymous 1973). Inclinometer measurements determined slope, and altimeter readings estimated elevations. Mesotopography was described for each stand.

A stand ordination was constructed using detrended correspondence analysis (DCA) (Gauch 1982, Hill 1979a: DECORANA program CEP 40 in the Cornell Ecology Program Series). A second program, TWINSPAN (Hill 1979b, program CEP 41 in the Cornell Ecology Program Series) provided a classification of the data using two way indicator species analysis, a polythetic divisive method. The TWINSPAN program defines species and stand groups. Five classes, with cut off levels of 2, 5, 10 and 20, were used in the TWINSPAN classification. The prominence values have been interpreted by this five class scale, based on the assumptions that a PV$\geq$20 is an important element in the community, and PV<2 is a minor element in the moss assemblage, indicating a rare or sparse occurrence of the species.

A subsequent analysis was run on the quantified data excluding 30 of the species, which occurred 3 times or less and had prominence values less than 3. The results indicated that the stand ordination

clusters and stand group classification remained virtually the same with the exception of one stand (C18). It was moved from stand group 1 to stand group 2. Thus, the rare species within the stands and stand groups are not a major influence on the stand group delineation. The entire data set was, therefore, used in the following analyses.

Correlations of the vegetation data and the physical parameters were done by the MINITAB Statistical Program (Ryan et al. 1982). The data appeared normal and were not transformed. In the following text correlation coefficients at p=0.01 are designated with **, at p=0.05 they are designated with *. The percent frequency of occurrence diagram was produced using methodology after Lausi and Nimis (1985) and Vitt et al. (1986).

RESULTS and DISCUSSION

Floristics

As a result of stand sampling and selective sampling of specialized habitats 114 species of mosses (117 taxa) were found on the fault block (Tab.II.III). Tanquary Fiord (125) and Lake Hazen (114) have similar species richness (Brassard 1971b, 1976, 1979; Tab.II.I). Thirteen new species are recorded for northern Ellesmere Island (Tab.II.III). Of these, five are disjunct from Alaska (Pohlia beringiensis, Pohlia filum, Schistidium subconfertum, Tayloria hornschuchii, Trichodon cylindricus (Shaw 1982, Cao and Vitt 1986, LaFarge-England and Vitt 1985, Ireland 1978).

Over 50% of the 117 taxa have rare or sparse occurrences on the fault block indicating the importance of these elements in terms of species richness of the upland. As well, the moss assemblages are predominantly composed of rare or sparsely represented taxa

(Tab.II.III). Observations of moss assemblages temperate streambed communities (Vitt et al. 1986) indicate a similar, important, rare element in bryophyte associations. Microhabitat availability and diversity have a significant effect on floristic diversity. Thus, collecting in specialized habitats (i.e. rock crevices, vertical peat faces, and scree slopes) significantly increases the number of species for the upland site.

Indirect Gradient Analysis

Stands

Initial gradient analyses of the 28 stands indicated that three stands (1,3,5) were outliers to the main data set. These three stands occur on bedrock and represent the most xeric moss assemblages in the study area. With the exception of a discussion of species richness, these stands were removed from the subsequent analysis. The following discussion is based on data from the remaining 25 stands.

A two dimensional DCA ordination of the stands is presented in figure 9. The eigenvalue for the first axis (x) is 0.80, whereas the second axis (y) has an eigenvalue of 0.56. The eigenvalue for the third axis (not shown), is considerably smaller at 0.26. The physical data of % soil moisture, slope, % organic content, sodium, and species richness values are superimposed on the stand ordiatiion in DCA (Figs.II.12-16)

A correlation matrix between the two principal axes of the moss stand ordination and the physical and chemical data (percent soil moisture, pH, percent organic content, texture (sand, silt, and clay), available soil nutrients (Ca, Mg, Na, K), cation exchange capacity (CEC), slope, and species richness) is presented in Table II.II. Due to the limited number of water samples (12), n is lower for the parameters

of water pH and conductivity. Significant correlations exist between the x-axis and 3 parameters, and between the y-axis and 2 parameters. Of these, with the exclusion of the conductivity data due to the limited number of data, the strongest correlation (r=0.68**) is between soil moisture (log values) and the x-axis with the exclusion of conductivity due to the limited number of samples. Soil moisture values superimposed on the stand ordination indicate an increasing gradient of moisture along the x-axis (Fig.II.12). Water availability has been considered the most important, single environmental factor controlling the distribution of arctic mosses (Steere 1978, Vitt and Pakarinen 1977). This hypothesis is supported by the present data.

A significant correlation (r=0.48*) exists between the y-axis of the ordination and slope (Fig.II.13). As well, organic content of the soil, is significantly correlated with the y-axis (r= -0.50**) (Fig.II.14) and also with soil moisture (r=0.54**). The interdependence of the physical parameters is emphasized by the relationship between % soil moisture, slope, and % LOI (Tab.II.II).

Soil pH, ranging from 4.55 to 7.70 does not show any significant correlation with the stand distribution (Tab.II.II). Variation in water pH is small, ranging from 6.3 to 7.1. A comparison of the water chemistry data with mire ecosystems farther south suggests that the southern Piper Pass sites lie within the range of rich fens (Sjors 1950, Slack et al. 1980, Vitt and Slack 1975). Specific conductivity readings of the 12 possible H_2O samples taken from the 28 stands show a positive correlation with the x-axis (r=0.86**), increasing along the xeric-hydric gradient. A comparison of the specific conductivity readings with Scandinavian mires (Sjors 1950) indicates that the hydric

stands can be classified as transitional rich fens.

The available nutrient content of ash shows one significant correlation with the vegetation axes; sodium is correlated (r=0.44*) with the x-axis (Tab.II.II, Fig.II.15). The remainder of the cation elements show the interdependence of the physical and chemical factors. Calcium is significantly correlated with soil moisture, organic content, and CEC (Tab.II.II). Calcium is the most abundant element in the soil, ranging from 3.80 to 45.00 meq/100gr ($\bar{x}$= 15.20). Therefore high values of Ca produce high values of CEC, resulting in a strong correlation. Magnesium is the second most abundant element, ranging from 0.38 to 13.14 meq/100gr. ($\bar{x}$ = 1.74), while sodium values are low, ranging from 0.01 to 0.18 meq/100gr. ($\bar{x}$ = 0.06). Potassium ranges from 0.28 to 1.74 meq/100gr. ($\bar{x}$ = 0.87). The total CEC (cation exchange capacity) reaches a maximum of 47.80 meq/100gr. and a minimum of 5.10 meq/100gr. These figures indicate the low nutritive status of the soil, and are typical of arctic soils (Bliss et al. 1984, Tedrow 1977).

Soil texture analysis (<2mm fraction), indicates that there are no significant correlations between texture classes and the vegetation data. Sand ranged from 34-88%; silt from 8-58%; and clay from 0-13%. The major variation in texture is between sand and silt, as indicated by the negative correlation (r=10.93**, Tab.II.II), whereas the clay content remains relatively constant. The predominance of sand and silt, derived from the recessive Permian sandstone, produces a coarse, poorly developed soil.

Mesotopography does not have a direct relationship with stand distribution. Extremes in mesotopography were classified in similar stand groups, based on the moss vegetation: gently sloping seepage

flats (Fig.II.5) with steeply graded, poorly developed hollows and mounds (Fig.II.6); and a steeply graded streambed (Fig.II.7) with a steep gulley (Fig.II.8). It is the microhabitats within the mesotopography which are critical to moss distirbution patterns.

The results of the chemical and physical data indicate that soil moisture, conductivity, and sodium are correlated with the x-axis, whereas slope and organic content are correlated with the y-axis. Mesotopography, texture, soil pH, calcium, potassium, magnesium, water pH and CEC are not significantly correlated with the stand distribution (either the x or y axis). From the correlation data (Tab.II.II) there are 12 significant correlations amongst the physical and chemical data. Therefore, the interdependence of these physical parameters suggests a complex arctic ecosystem and its resulting vegetation distribution.

Stand Groups

The stands were classified into five stand groups having eigenvalues above by TWINSPAN. The relationships between these groups is illustrated by a dendrogram (Fig.II.11). The centroid values of the stand groups are presented in figure II.10, indicating their spatial relationship. The distribution of the stand groups is primarily related to the moisture gradient along the x-axis and to slope along the y-axis. Slope is correlated with the y-axis. The lowest soil moisture values occur in stand group 2, to the left of the ordination, whereas the highest values in stand group 5, at the right (Figs.II.10,12). The lowest slope values occur in stand group 5 having low y-axis values, whereas the highest slope values occur in stand group 4, having high y-axis values (Figs.II.10,13).

Stand Group 1:

The indicator species of stand group 1 is Racomitrium canescens. The group is dominated by Hypnum revolutum, with Tortula ruralis and Distichium capillaceum also prominent. These species also have widespread occurrences within other stand groups. Thirty percent of the species in stand group 1 are restricted to it (Tab.II.III), but have low prominence values (<5). This suggests that stand group 1 has a significant and characteristic element.

Stand Group 2:

Tortula ruralis and Drepanocladus uncinatus are both the dominant and indicator species of stand group 2. Ditrichum flexicaule, Distichium capillaceum, and Encalypta rhaptocarpa also have high prominence within the group. Sixteen percent of the species are restricted to stand group 2 and these have low prominence values (<5).

Stand Group 3:

Timmia austriaca, Pogonatum alpinum, and Philonotis fontana var. pumila are the indicator species of stand group 3. These are also the dominant species, along with Bryum pseudotriquetrum. Seven percent of the species are restricted to stand group 3 (Bartramia ithyphylla, Dicranum elongatum, and Dicranella crispa), each having a prominence value of less than 2.

Stand Group 4:

TWINSPAN does not assign any indicator species for stand group 4, however it is characterized by the strong dominance of Philonotis fontana var. pumila (PV≥20). In addition, Bryum pseudotriquetrum, Calliergon giganteum, Bryum cryophilum, Aulacomnium palustre, Timmia bavarica and T. austriaca occur in the stand group. Only 6% of the

species are restricted to stand group 4: Hygrohypnum polare and Schistidium rivulare ssp. latifolium (Tab.II.III).

Stand Group 5:

Two indicator species characterize stand group 5, Drepanocladus revolvens and D. brevifolius. Campylium arcticum, Calliergon giganteum, Philonotis fontana var. pumila, and Cinclidium arcticum are common in the stand group. 21% of the quadrat species were restricted to stand group 5 (Tab.II.III).

Stand groups 1, 2, and 3 are xeric - mesic to mesic, reflected in soil moisture values, while stand groups 4 and 5 are mesic - hydric to hydric (Figs.II.10,12). Stand group 5 has the lowest slope values with a mean slope of 3^{o}. Stand groups 1 and 3 have mean slope values of 19^{o} and 14^{o}, respectively; stand group 2: 27^{o} and stand group 4: 25^{o}. These values reflect an increase in slope along the y-axis of the ordination (Fig.II.13). There is a trend of increasing organic content with decrease in slope (Figs.II.13,14; Tab.II.II).

Stand Group/Species Richness

The mean values for species richness of the stand groups are as follows: 1) 17.4 ($\pm$6.8), 2) 16.4 ($\pm$9.0), 3) 21.2 ($\pm$6.4), 4) 18.3 ($\pm$6.5), 5) 18.7 ($\pm$6.8). The mean of the outlier stand group (stands 1,3,5) is ($\bar{x}$=4.7 ($\pm$0.6). Mean species richness is lowest in stand groups 1, 2, and 5, and highest in stand group 3, indicating a slight increase with mesic conditions (Figs.II.10,16). However, a test of means (ANOVA) on the five stand groups indicates no significant differences. The absence of overlap between the outlier stand group data and the 5 stand groups' data, shows the truly xeric habitats support a restricted moss flora. Therefore, there is a significant

difference in species richness for the truly xeric moss assemblages, but no differences within the xeric - mesic to mesic - hydric gradient. Similar results were presented for the moss assemblages of the Truelove Lowland, on Devon Island (Vitt and Pakarinen 1977).

Species Groups

From the TWINSPAN classification, seven major species groups are identified (Tab.II.III). The species groups are clusters of taxa with similar distribution patterns throughout the stand groups. The stand group ordination has shown a correlation with % moisture and sodium (x-axis) and slope and % organic content of soil (y-axis). Therefore, the distribution of species groups within the stand groups within suggests species preferences for the correlated parameters. A percentage frequency diagram (Fig.II.17) illustrates the relative composition of species groups within a given stand group by means of adjusted scores to equal block size (Lausi and Nimis 1985, Vitt et al. 1986). It also shows the distribution of a given species group throughout the stand groups, indicating a restricted versus widespread pattern of the species within the group.

Xeric-Widespread: Species group 1. This group includes Bryoerythrophyllum recurvirostrum, Encalypta rhaptocarpa, and Tortula ruralis, all of which are widely distributed throughout the stand groups. These species occur predominantly in stand groups 1 and 2, indicating a relatively xeric preference of species in this group (Fig.II.17).

Xeric Restricted: Species group 2. Hypnum revolutum is the dominant species of species group 2. This group has its highest percent frequency occurrence in stand group 1 (Fig.II.17), reflecting

xeric preferences of these species. Thirteen of the 17 species are restricted to stand group 1, indicating the xeric-restricted pattern of distribution. The species of this group are absent from stand group 5, which is the most hydric.

Xeric-mesic Restricted (Rare): Species group 3. The species of this group are associated with stand groups 2 and 3 and are absent from stand groups 4 and 5 (Fig.II.17). Nine of the 15 species are restricted to stand groups 2 and 3. All of the species within this group have low prominence values (<2), with the exception of Thuidium abietinum. The occurrence of Tayloria hornschuchii, Stegonia latifolia var. pilifera, Saelania glaucescens, Bryobrittonia longipes, Dicranum elongatum, and Dicranella crispa are all considered rare on northern Ellesmere Island (Brassard 1971b, LaFarge-England and Vitt 1985), suggests the rare character of this species group.

Mesic Widespread: Species group 4. Hylocomium splendens, Pogonatum alpinum, Timmia austriaca, Ditrichum flexicaule and Drepanocladus uncinatus are the most prominent species of the group. Species group 4 shows its strongest association with stand groups 1, 2, and 3 (Fig.II.17). In stand group three, these mesic widespread species are the most important contributors. The association with stand group three suggests the preference of mesic growing conditions for the species. Species group 4 has a mean percent frequency of occurrence 20.6 $\pm$ 4.9% (Fig.II.17) throughout the stand groups, indicating its prominent widespread occurrence.

Hydric-mesic Widespread: Species group 5. This group is composed of only three species Aulacomnium acuminatum, Bryum pseudotriquetrum and Orthothecium chryseum var. chryseum. The group has

its strongest affiliation with stand groups 3, 4, and 5 (Fig.II.17). The widespread occurrence of species group 5 throughout the five stand groups suggests tolerances to broad ranges of soil moisture and slope conditions, but the prominence values indicate a preference for the more hydric conditions.

Hydric Restricted: Species group 6. The species of this group are primarily restricted to stand groups 4 and 5, with rare occurrences in 1, 2 and 3. Stand group 5 has 20% of its species percent frequency occurrences from the hydric restricted species (Fig.II.17).

Six of the 16 species within the restricted hydric group are found in stand group 5, which is characterized by low slope values and high percent soil moisture values. Only 2/16 are restricted to stand group 4, which is characterized by high slope and percent soil moisture values. The data show the preference of these species for the hydric stand groups 4 and 5 (Fig.II.17).

Hydric Widespread: Species group 7. This group is composed of four species: Brachythecium turgidum, Philonotis fontana var. pumila, Plagiomnium medium, and Timmia sibirica. It is most strongly correlated with stand groups 3, 4, and 5. These species are the dominant component of stand group 4 (28% frequency occurrence), and have secondary importance in stand group 3. Philonotis fontana var. pumila is the dominant species of species group 7, occurring throughout the stand groups, but with a strong dominance in stand group 4. Streambed habitats with the highest slope values are where Philonotis fontana var. pumila is found in pure turfs. In both stand groups (3 and 5), Philonotis fontana var. pumila grows intermixed with other taxa.

The distribution of the dominant species within each of the five

stand groups illustrates the distinct species patterns associated with each stand group (Figs.II.18-22).

Direct Gradient Analysis

A direct gradient analysis of the vegetation along a transect above and below a persistent snowbank on a 80 meter slope (Figs.II.4,23), illustrates distinct species distribution patterns. These patterns can be directly related to particular physical parameters. Encalypta rhaptocarpa, Racomitrium canescens, and Hypnum revolutum are restricted to stations sampled above the late-lying snowbank (stations 14-16); these have relatively low moisture, low slope values, and low % organic content. Philonotis fontana var. pumila, Aulacomnium acuminatum, A. palustre, Brachythecium turgidum, and Tomenthypnum nitens occur predominantly in the zone directly below the late-lying snow bank and above the seepage flats (stations 5-12). The physical parameters, of this zone, include relatively high slope values, variable clay content, consistent pH values and relativly high organic content. Drepanocladus brevifolius, D. revolvens, and Bryum cryophilum are restricted to the seepage flats below the late-lying snowbank slope. The corresponding stations (1-4) indicated characteristic low slope values, consistent pH values, low % organic content values, and submerged, saturated soils. The % soil moisture values do not reflect expected high values for submerged stations.

An important factor with respect to soil moisture variability along the transect slope is the active layer, which has a direct effect on the height of the water table. Above the late-lying snowbank the depth of thaw was a minimum of 10 cm. Immediately below the late-lying snowbank the ground was virtually frozen to the surface. Thus, apical

portions of the mosses were saturated with meltwater. Brachythecium turgidum is known as a hydrophyte (Kuc 1973) and indicates the moisture regime of the slope. It is predominant in the upper slope stations and decreases its abundance down slope as the active layer increases in depth and the channelling of the meltwater becomes established on the hummocky terrain. The seepage flats at the bottom of the slope are inundated with 2 - 3 cm of meltwater throughout the growing season, regardless of the deep active layer (60 cm). The seepage flat stations are subject to disturbance which effects the cover. As well, soil particles are washed down slope, accumulating as an active solifluction sheet. Fluctuations in the water level throughout the growing season may also contribute to the low cover of the hydric species.

The data indicate that the distribution of species along the transect reflects the interdependence of a number of physical factors which creates specialized niches for the bryophytes. These patterns are restricted in some (i.e. Racomitrium canescens, Aulacomnium acuminatum, or Drepanocladus brevifolius), and widespread in others (i.e. Tortula ruralis and Philonotis fontana var. pumila, Fig.II.17). Thus, the distribution of species occurrences along the transect reflects a variety of responses to the measured physical parameters.

The TWINSPAN classification of the transect data resulted in four groups of stations: 15a, 15b, 15c, 15d (Fig.II.23). These data sets were incorporated into the total vegetation data and classified with the stand data. The seepage flat stations (15a) were classified in stand group 5; the lower slope stations (15b) were classified into stand group 4; the upper slope stations (15c) were classified in stand group 3, and the stations above the late-lying snowbank (15d) were

classified in stand group 1. This stand patterning, again, indicates that moisture is the limiting factor in determining species assemblages of the slope.

Comparative studies

A comparison of the transect slope data (80 m in elevation) to the beach ridge transect (10 m in elevation, Miller and Alpert 1984) and the Truelove Lowland (Vitt and Pakarinen 1977), indicates that hydric sites with low slope values have similar species assemblages. Drepanocladus brevifolius, D. revolvens, Campylium arcticum, and Cinclidium arcticum represent the dominant species of this ubiquitous, high arctic, wet meadow, moss assemblage. The data presented here indicate that the mesic and xeric moss assemblages are variable when compared to those from the Devon Island and Bathurst Island. Miller and Alpert's slope assemblages have a dominance of Tomenthypnum nitens and Aulacomnium acuminatum, while in the present site Philonotis fontana var. pumila, Aulacomnium acuminatum and A. palustre are the dominant mosses of the lower portion of the slope. The upper portion of the slope is dominated by Pogonatum alpinum, Brachythecium turgidum, Philonotis fontana var. pumila, Bryum pseudotriquitrum and Tortula rualis. As well, the highest percent cover of mosses is on the slope of the transect as opposed to the saturated, level, seepage flats. The seepage flats are similar to the high arctic, wet meadow, moss assemblages, but have a more restricted cover due to the disturbance of the solifluction sheet movement (Fig.II.4).

The stations above the late-lying snowbank are dominated by Ditrichum flexicaule, Hypnum revolutum, and Tortula ruralis. These species are similar to the dominant crest mosses of Miller and Alpert

(1984), though the other moss components of the assemblage differ.

Truly xeric species assemblages have a restricted diversity (stands 1,3,5, this study). Grimmia spp. Schistidium apocarpum, Orthotrichum speciosum are the common elements of the high arctic, extremely xeric, moss assemblages (Holmen 1960, Kuc 1973, Brassard 1971a).

Application for Subfossil Moss Assemblage Analyses

The present quantified study of moss assemblages of the Piper Pass fault block have been used to relate the Holocene peat deposits on the site (LaFarge-England 1988) to the extant moss assemblages of the upland. The contemporary moss assemblages, as defined by the stand groups and correlated with the physical parameters can indicate relative gradients especially that of xeric to hydric conditions, under which the subfossil assemblages occurred. By understanding the contemporary moss assemblages, species composition of stands and individual tolerances of physical conditions, conditions under which the subfossil assemblages were established may be inferred.

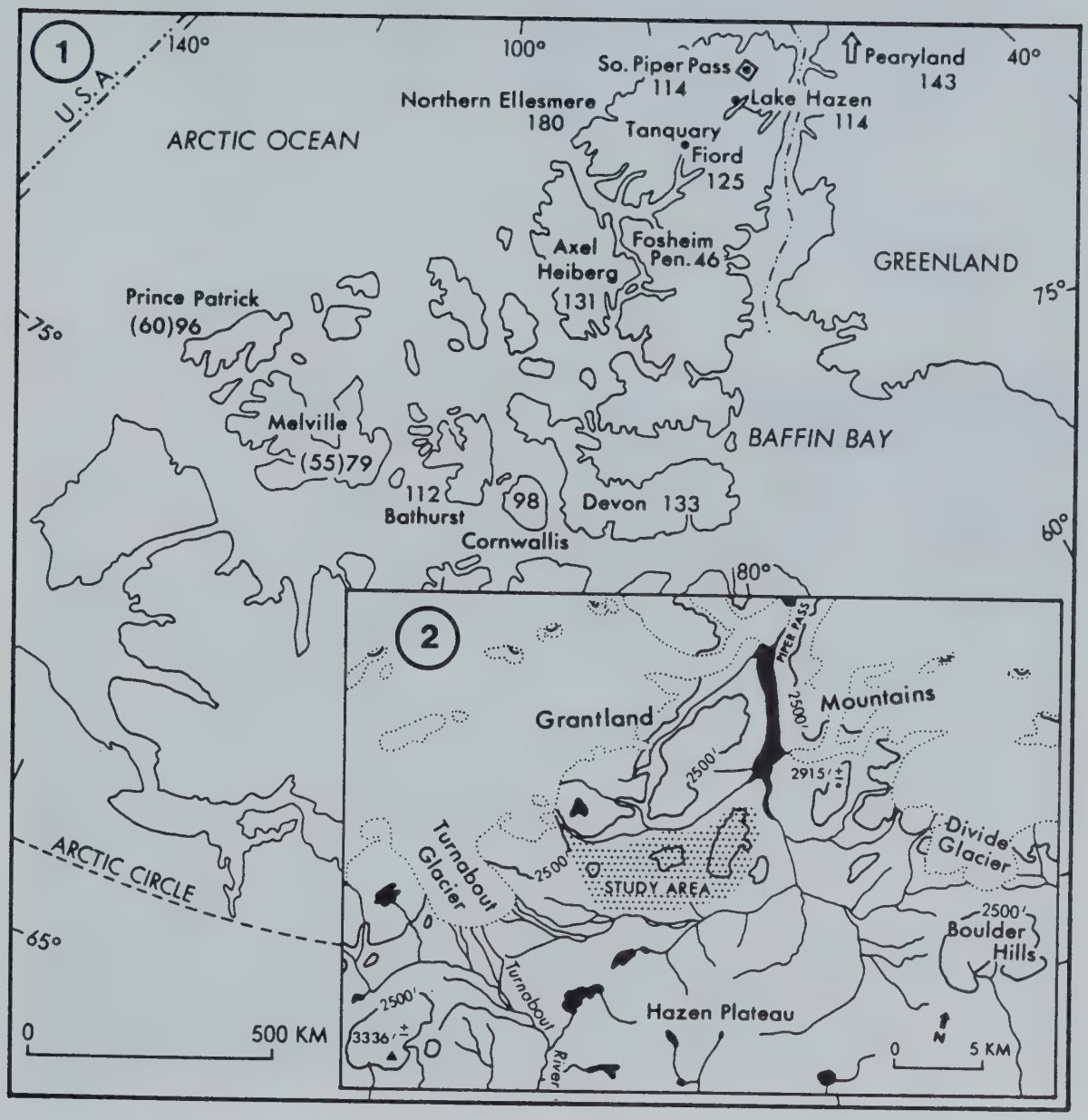
SUMMARY

The quantitative study of moss associations in a high arctic, upland locality (450 - 900 m) of 35 km^2, has indicated that 25 out of 28 sampled stands can be divided into 5 major stand groups, and the moss species into 7 major species groups. An indirect gradient analysis of the physical parameters indicates that the x-axis of the ordination of the stand groups (Fig.II.10) is most strongly correlated with a moisture gradient (xeric-mesic to hydric, Fig.II.12) and that the y-axis is positively correlated with slope (low to high, Fig.II.13) and negatively correlated with organic content (Fig.II.14). Additional significant correlations of the moss assemblages are with sodium

(Fig.II.15) and specific conductivity. The other significant correlations indicate interdependence of physical, chemical, and vegetation data (Tab.II.II). A direct gradient analysis of the vegetation along moisture and slope gradients illustrates the selective distribution of moss species to these factors (Fig.II.23).

The realized niche of each taxon is controlled by both environmental variables and species interactions. The analysis of the former indicates several species patterns. The species are classified into 7 species groups indicating different distribution patterns and preferences (Fig.II.17). Two basic patterns are evident, widespread versus restricted and hydric versus xeric.

The present study on the contemporary moss assemblages of the southern Piper Pass upland forms a detailed data base on species richness, species distribution patterns, species groups and stand groups. Physical and chemical parameters clarify some of the species patterns within the stands. The examination of the individual species throughout the stands, indicates preferences and tolerances to environmental variables. These data are critical for interpreting the subfossil deposits which occurr at the same locality (LaFarge-England 1988). Comparative studies from other high arctic localities elucidate the degree of variation within the diverse high arctic landscape.



Figs.II.1 and 2. Fig. 1. Location of study area. Numbers refer species reported for investigated islands of the high arctic, northern Greenland, and 4 localities of northern Ellesmere Island (See Tab.II.I). Southern Piper Pass refers to the study area locality, indicated by a diamond. Fig. 2 (inset). The study area (shaded) is located at the southern end of Piper Pass, south of the Grantland Mountains and North of the Hazen Plateau, between the Turnabout Glacier and the Divide Glacier.

Fig.II.3. Oblique air photo of fault block at the southern end of Piper Pass (upper right of picture). The arrows point to the Permian sandstone margin of the fault block. The solid line refers to the diabase dyke protruding through the fault block.

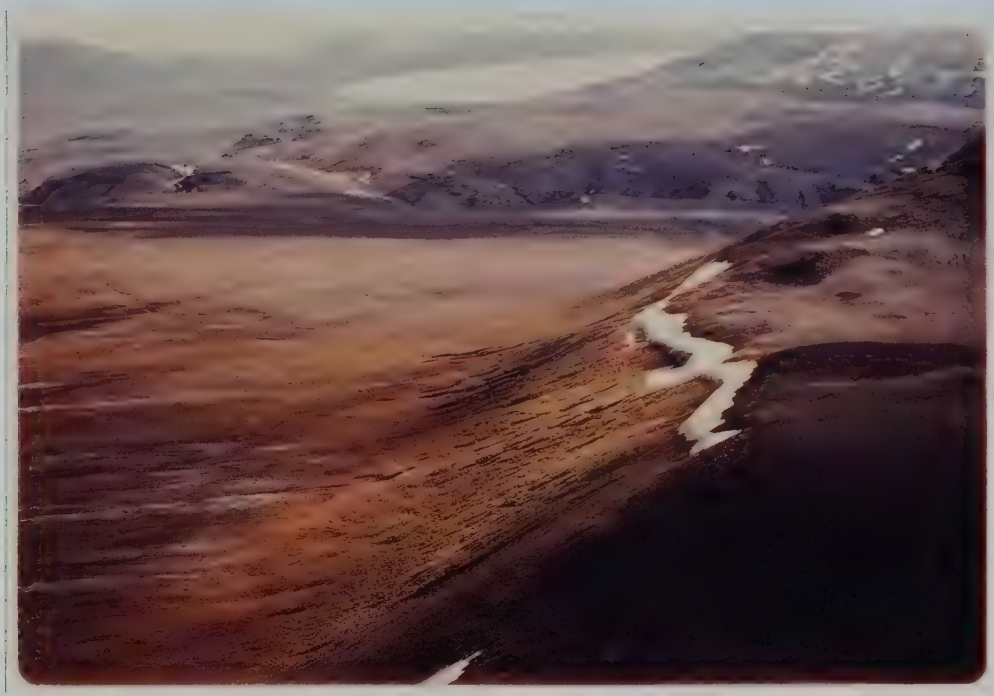
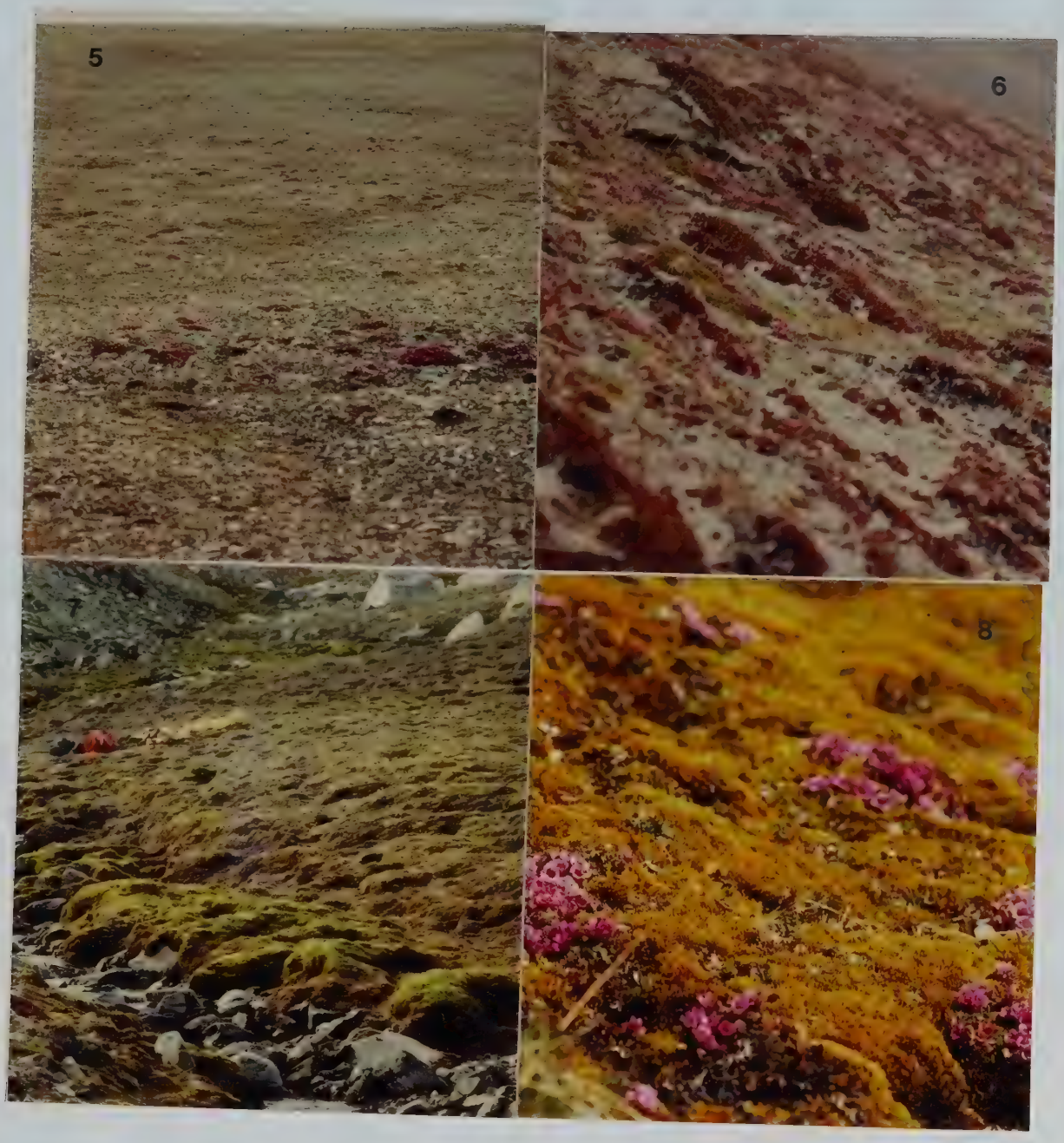
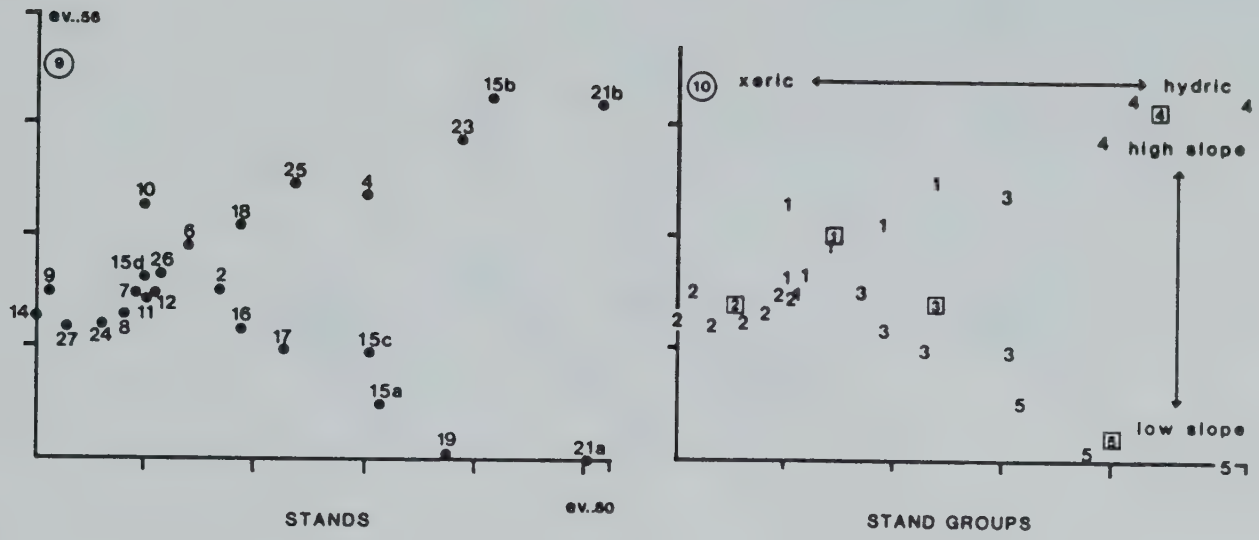


Fig.II.4. A profile of the 80m slope (C15), on which the transect for the direct gradient analysis was sampled.



Figs.II.5-8. Habitat diversity. Fig. 5. Stand C12 showing minimal slope and slight surface undulation. Fig. 6. Stand C6 showing steep slope, with moderate mound-depression development. Fig. 7. Stand C21b showing streambed habitat with Philonotis fontana var. pumila forming pure turfs along margins. Fig. 8. Stand C23 showing seepage gulley dominated by Philonotis fontana var. pumila and Aulacomnium acuminatum.



Figs.II.9-10. Fig. 9. A two dimensional plot of the stands, representing the first two axes of the detrended correspondence analysis. Fig. 10. TWINSPAN classification superimposed on the DCA ordination. The boxed numbers refer to the centroid values of the stands within a given stand group. Moisture and slope gradients are indicated.

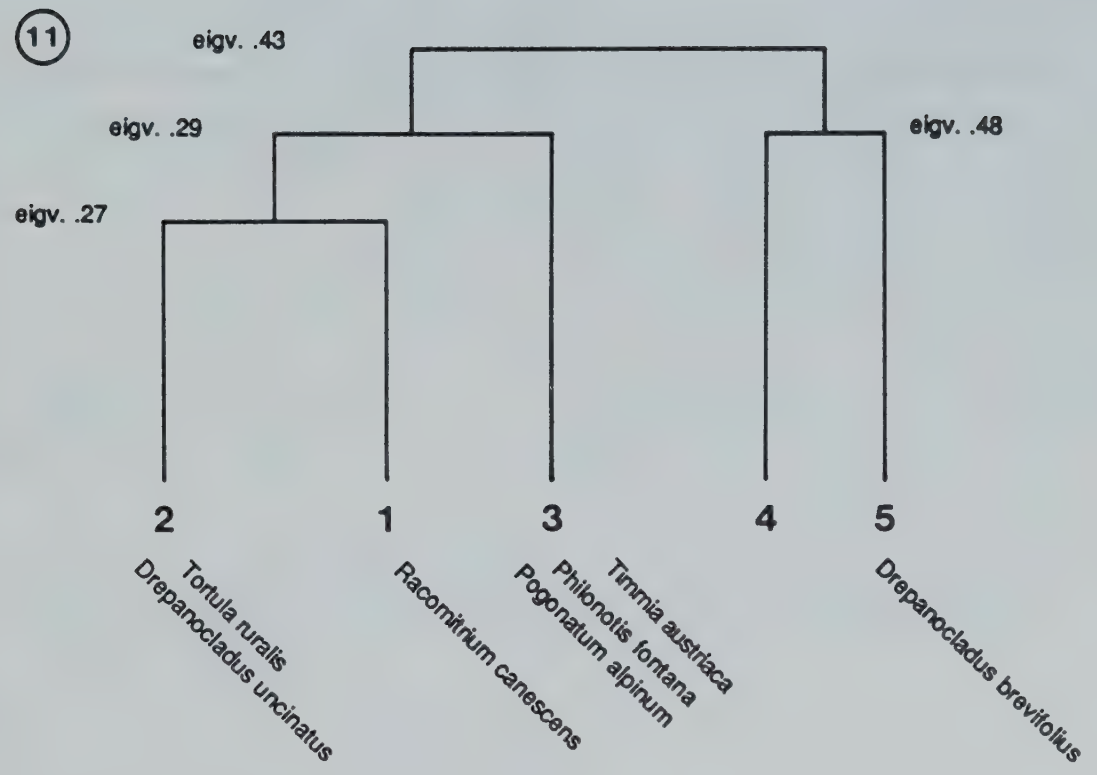
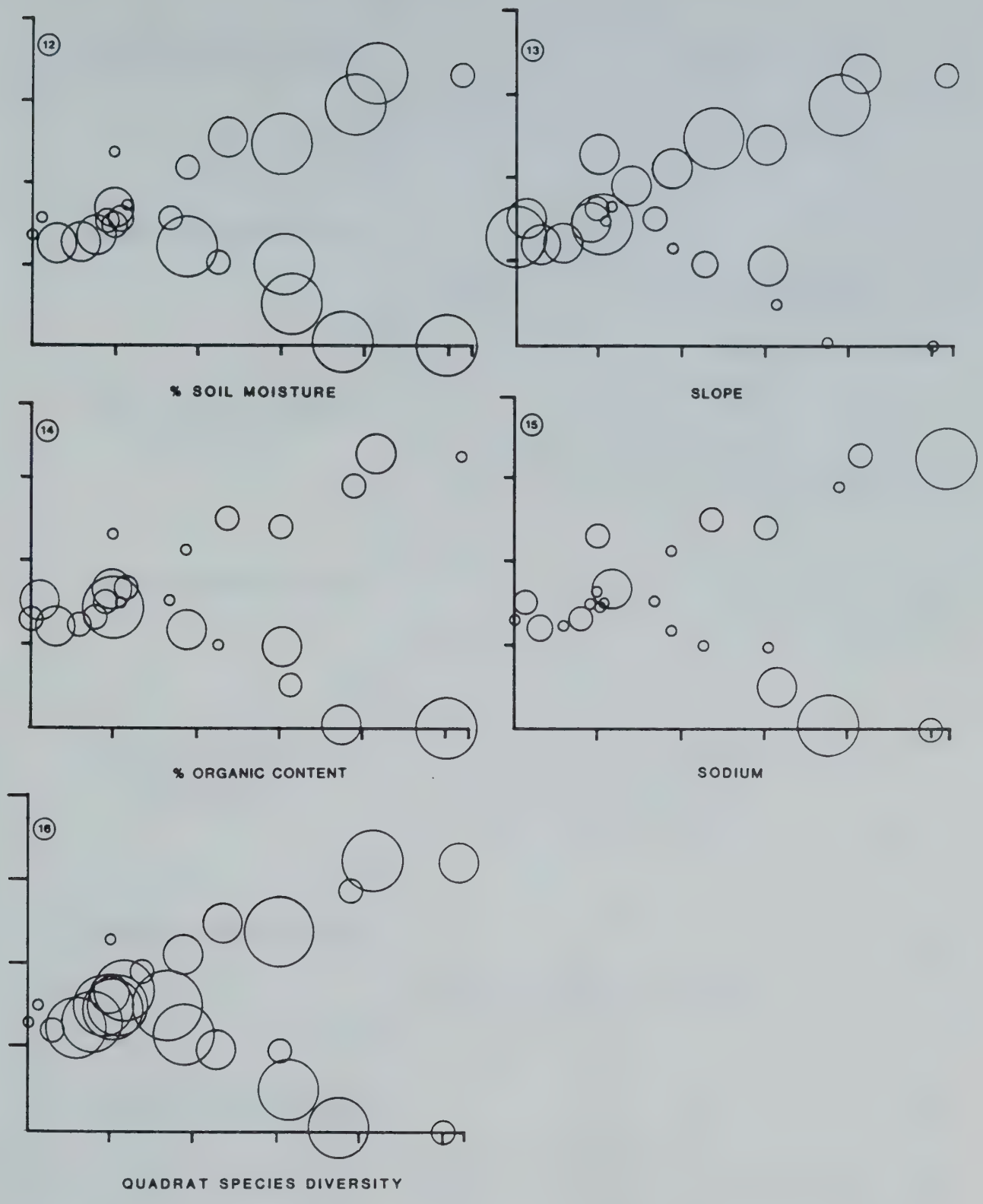


Fig.II.11. A dendrogram of the TWINSPAN classification of the stand groups. Eigenvalues are given for each level of the classification. Indicator species as designated by TWINSPAN are given for each stand group. The horizontal distance between the is the centroid distance of the first axis (x-axis) of the DCA ordination (Lausi and Nimis 1985).



Figs. 12-16. Physical parameters have been superimposed upon the DCA stand ordination. Four classes have been used for circle size variation, with 1 representing the smallest and 4 the largest. Fig. 12. Percent soil moisture circle size 1: $\leq$15, 2: 15$\leq$40, 3: 40 $\leq$70, 4: >70. Fig. 13. Slope circle size 1: <10^{o}, 2: 10^{o} <20^{o},3: 20 <30^{o}, 4: $\geq$30^{o}. Fig. 14. Percent organic content circle size 1: $\leq$5, 2: >5-10, 3: >10-20, 4: >20. Fig. 15. Sodium meq. per 100 gr. circle size 1: 0-0.05, 2: >0.05-0.09, 3: >0.09-0.15, 4: >0.15. Fig. 16. Quadrat species diversity circle size 1: 0-9, 2: 10-15, 3: 16-20, 4: $\geq$21.

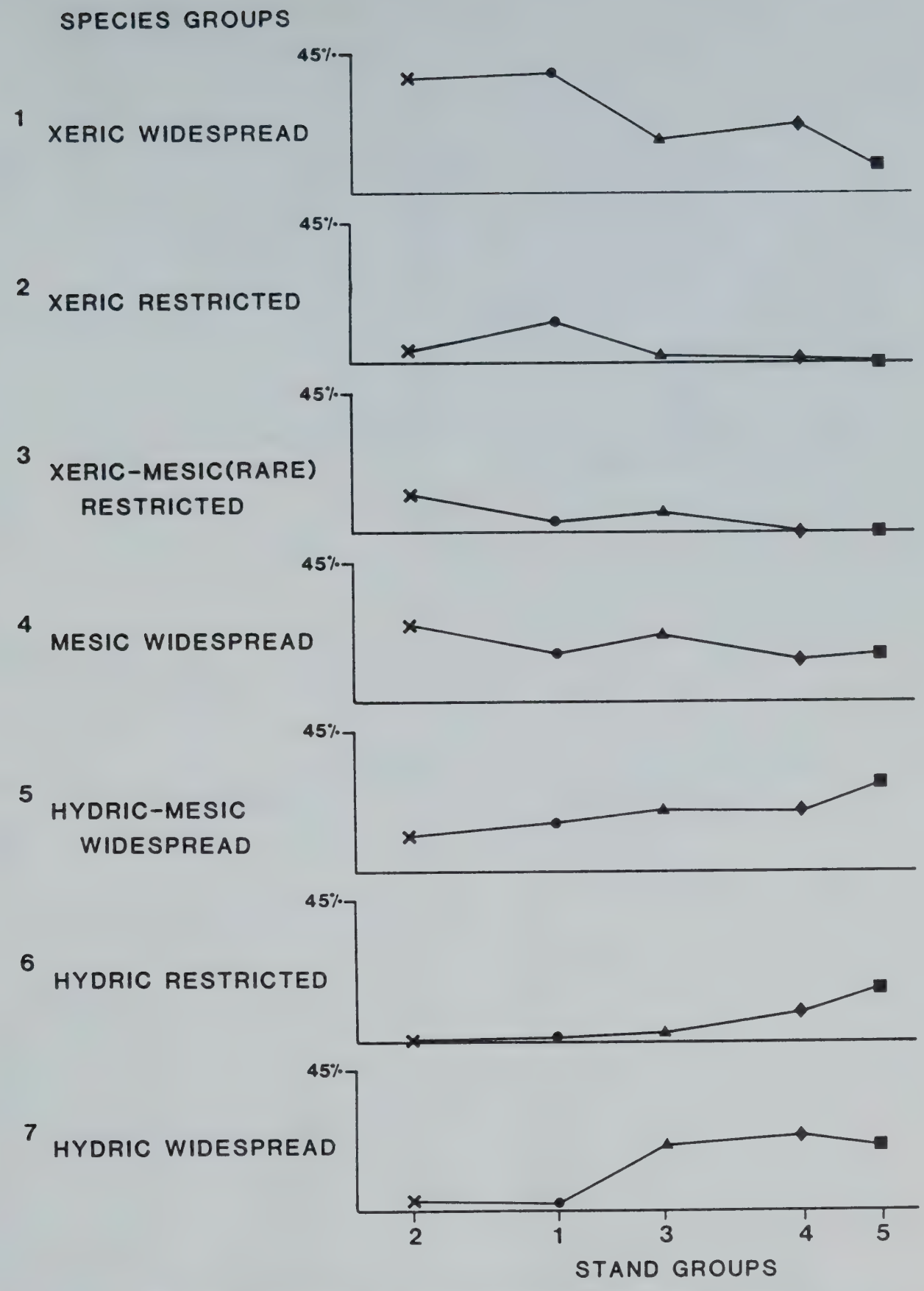
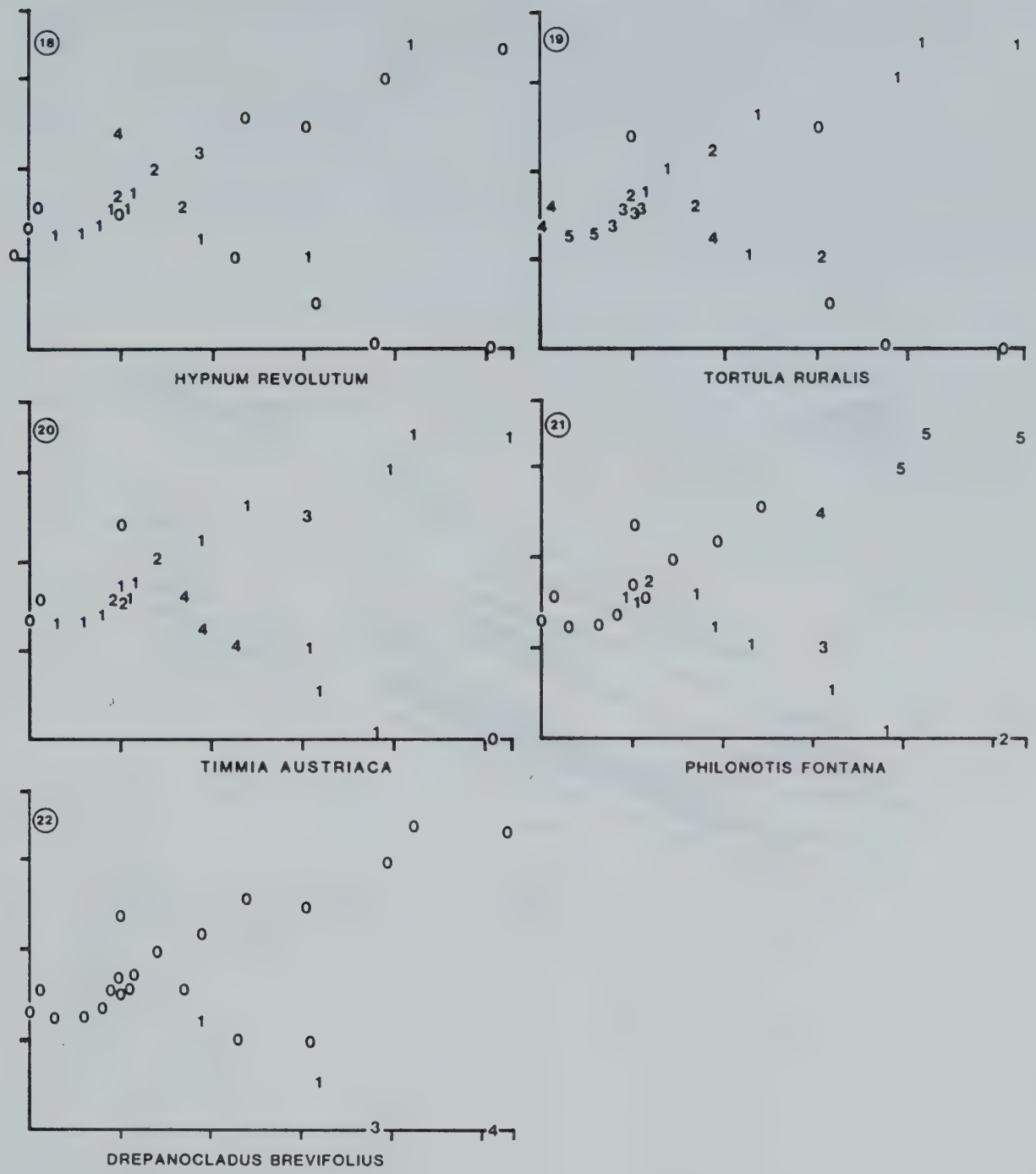


Fig.II.17. Percent frequency of occurrence of species in stand groups. Stand groups are shown along the DCA x-axis, with each species group shown as percent frequency of occurrence along the y-axis (Lausi and Nimis 1985). A single stand group is represented by varying percents of each species group, having a total of 100% from all 7 species groups.



Figs.II.18-22. Figs. 18-22. Species mapped throughout the stands by a 5 class system as designated by TWINSPAN. Classes are expressed in prominence values as follows: 0: not present, 1: PV $\leq$2, 2: PV >2 $\leq$5, 3: PV >5 $\leq$10, 4: PV >10 $\leq$20, 5: PV >20.

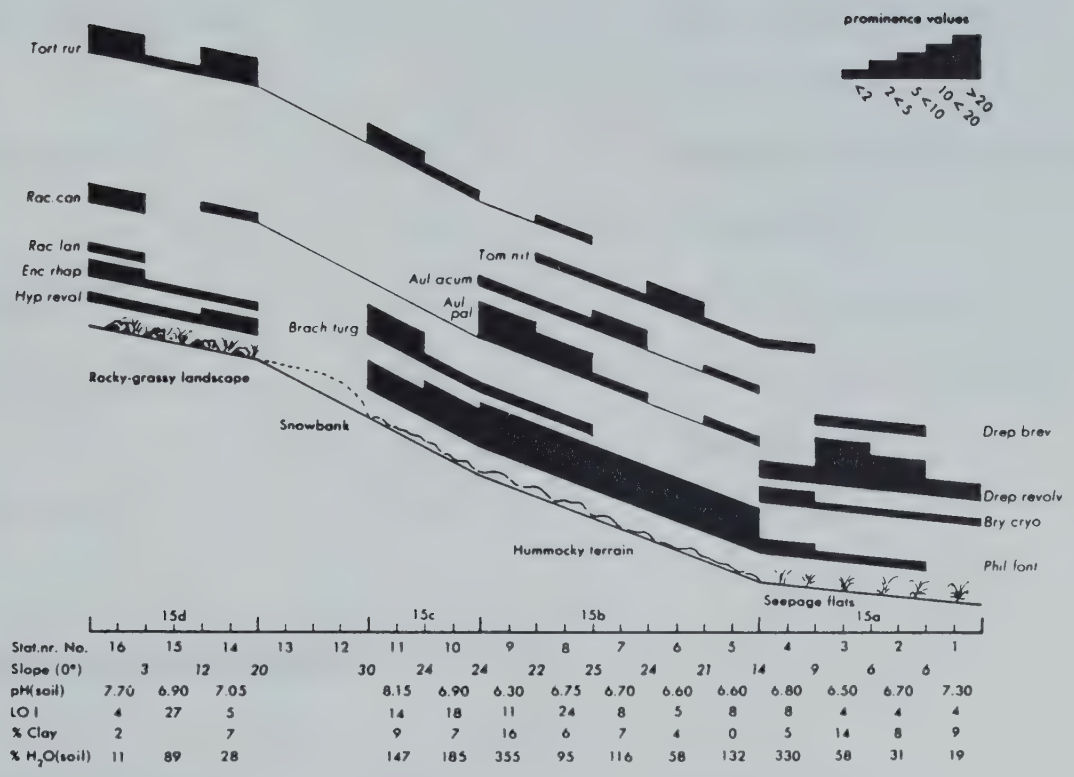

prominence values
≤2
2<5
5≤10
10<20
>20
Tort rur
Rac can
Rac lan
Enc rhap
Hyp reval
Brach turg
Tom nit
Aul acum
Aul pal
Rocky-grassy landscape
Snowbank
Hummocky terrain
Seepage flats
Drep brev
Drep revolv
Bry cryo
Phil font
15d
15c
15b
15a
Stat.nr. No. 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
Slope (°) 3 12 20 30 24 24 22 25 24 21 14 9 6 6
pH(soil) 7.70 6.90 7.05 8.15 6.90 6.30 6.75 6.70 6.60 6.60 6.80 6.50 6.70 7.30
LOI 4 27 5 14 18 11 24 8 5 8 8 4 4 4
% Clay 2 7 9 7 16 6 7 4 0 5 14 8 9
% H2O(soil) 11 89 28 147 185 355 95 116 58 132 330 58 31 19

Fig.II.23. A direct gradient analysis, showing the four groupings of the stations and physical parameters measured at each station on the transect. Species distributions are represented by bars. Thickness is determined by prominence values.

locality	mosses	reference
Pearyland, Greenland	143	Holmen 1960
Northern Ellesmere Isl.	180	Brassard 1971b,1976,1979 LaFarge-England (Tab.II.III)
Axel Heiberg Isl.	131	Miller and Ireland 1978
Prince Patrick Isl.	60, 96	Bird 1975, Miller and Ireland 1978
Melville Isl.	55, 79	Brassard 1967, Miller and Ireland 1978
Bathurst Isl.	112	Miller and Ireland 1978
Cornwallis Isl.	98	Steere 1951, Miller and Ireland 1978
Devon Isl.	133	Vitt 1975
Central Ellesmere Island		
Fosheim Peninsula	46	Holmen 1953
Lake Hazen	114	Brassard 1971b, 1976
Tanquary Fiord	125	Brassard 1971b, 1976
Southern Piper Pass	114	LaFarge-England (Tab.II.III)

Table II.I. Number of moss species for localities in the Canadian Arctic Archipelago and northern Greenland.

	x	y	pH	H_2O	LOI	sand	silt	clay	slope	q moss	Ca	Mg	Na	K
y	0.145													
pH	-0.109	0.382												
H_2O	*<u>0.579</u>	-0.242	-0.039											
LOI	0.202	<u>-0.503</u>	0.032	<u>0.544</u>										
sand	0.014	0.090	0.096	-0.163	-0.354									
silt	0.026	-0.086	-0.073	0.153	0.303	<u>-0.930</u>								
clay	-0.360	-0.017	0.035	-0.082	0.165	<u>-0.427</u>	0.201							
slope	-0.250	<u>0.477</u>	0.337	-0.327	-0.181	-0.059	-0.055	0.164						
q moss	0.102	0.032	-0.371	0.029	-0.024	0.008	-0.004	0.004	<u>-0.435</u>					
Ca	0.165	-0.263	0.228	<u>0.604</u>	<u>0.502</u>	-0.154	0.170	0.005	-0.119	-0.272				
Mg	0.287	0.324	0.084	0.342	0.259	-0.173	0.186	0.063	-0.036	0.197	0.338			
Na	<u>0.441</u>	-0.017	-0.177	-0.075	0.006	-0.162	0.153	-0.117	-0.397	0.042	-0.034	0.007		
K	0.360	-0.369	-0.162	0.198	0.324	-0.274	0.350	-0.144	<u>-0.569</u>	0.100	0.258	0.213	<u>0.676</u>	
CEC	0.224	-0.176	0.217	<u>0.622</u>	<u>0.516</u>	-0.185	0.205	0.013	-0.135	-0.196	<u>0.977</u>	0.528	-0.003	0.312

*(ln H_2O r=0.68 with x-axis)

Table II.II. Correlation coefficients (r) for physical parameters from soil samples. Statistically significant values at 0.01 level are underlined twice, those at 0.05 are underlined once, n=22. X is axis one of the stand data; y is axis two of the stand data; pH is data from the soil samples; H_2O refers to % soil moisture; LOI is estimation of percent organic content of the soil samples; sand, silt and clay refer to the texture composition of the soil samples; q moss refers to the number of moss taxa determined from the quantitative data; ln H_2O refers to a logarithmic scale of percent soil moisture; Ca, Mg, Na, K are the mineral components determined from the soil samples; CEC is the cation exchange capacity.

Table II.III. Distribution of mosses within the stand groups and species groups and a list mosses from southern Piper Pass fault block. Occurrence values are represented by a five class system: prominence values ≤ 2 are in class 1; $>2 \leq 5$ in class 2; $>5 \leq 10$ in class 3; $>10 \leq 20$ in class 5. Moss taxa from the nonquantitative data are listed alphabetically. A single * indicates taxa new to northern Ellesmere Island, ** indicates taxa new to the Canadian Arctic Archipelago.

	STAND GROUPS																										
	1							2							3					4				5			
STANDS	18	10	6	12	5a	25	26	7	8	11	24	27	9	14	2	5c	16	4	17	5b	1b	23	5a	19	1a	
SPECIES																										SPECIES GROUPS
Bryoerythrophyllum recurvirostrum	-	-	1	1	1	1	1	1	1	1	1	-	-	-	1	-	-	1	-	-	1	-	1	-	-	
Encalypta rhaptocarpa	-	1	1	1	1	1	1	1	1	2	-	1	2	1	1	-	-	1	-	-	1	1	-	1	-	1
Tortula ruralis	2	-	1	3	2	1	1	3	3	3	5	5	4	4	2	2	4	-	1	1	1	1	-	-	-	
Aloina brevirostris	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Amphidium lapponicum	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Anoectangium tenuinerve	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Cyrtomnium hymenophyllum	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Desmatodon leucostoma	-	-	-	-	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Didymodon asperifolius	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Fissidens bryoides	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

	STAND GROUPS																												
	1							2								3						4				5			SPP
Grimmia plagiopodia	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	GRPS
Hypnum bambergeri	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Orthothecium strictum	-	-	-	1	-	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Orthotrichum speciosum	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Racomitrium canescens	1	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Racomitrium lanuginosum	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Schistidium apocarpum var. apocarpum	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Tortula mucronifolia	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Barbula icmadophila	-	1	1	1	-	1	1	1	1	1	-	-	1	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	
Hypnum revolutum	3	4	2	1	2	-	1	1	1	-	1	1	-	-	2	1	1	-	-	1	-	-	-	-	-	-	-	-	
Mnium thomsonii	1	-	-	-	-	-	1	1	1	-	1	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	
Bryobrittonia longipes	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Eurhynchium pulchellum	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

| | STAND GROUPS | | |

	STAND GROUPS																												
	1							2								3						4				5			
Ceratodon purpureus	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-		
Hylocomium splendens	1	-	-	-	-	-	-	-	1	1	-	1	-	-	-	-	-	4	3	1	-	-	-	-1	-	-	SPP		
Pogonatum alpinum	1	-	-	2	1	1	1	1	-	1	2	1	-	-	3	3	3	1	2	1	-	-	1	2	-	GRPS			
Timmia austriaca	1	-	2	1	1	1	1	2	1	2	1	1	-	-	4	1	4	3	4	1	1	1	1	1	-				
Distichium capillaceum	1	1	2	3	1	3	2	1	1	2	1	1	1	-	2	-	1	3	3	1	1	-	1	-	-				
Ditrichum flexicaule	2	1	1	1	2	1	1	1	1	1	1	3	1	-	1	-	1	2	4	1	-	-	2	1	-	4			
Drepanocladus uncinatus	1	-	-	1	1	-	1	2	3	3	3	2	-	-	1	2	2	1	2	1	-	1	-	1	-				
Encalypta procera	-	-	-	1	-	-	1	1	1	-	-	-	-	-	-	-	-	1	1	-	1	-	-	-	-				
Encalypta alpina	1	-	-	1	1	1	1	1	1	1	1	-	-	1	1	-	-	1	1	-	-	-	1	1	-				
Polytrichum juniperinum	-	-	-	-	-	-	-	-	-	1	1	1	-	-	1	1	1	-	2	1	-	-	-	1	-				
Aulacomnium turgidum	2	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2	-	-	1	-	-	-	1	-				

	STAND GROUPS																													
	1							2								3						4				5				
																														SPP
Myurella tenerrima	1	-	-	1	-	1	1	-	-	1	1	1	-	-	-	-	1	1	1	1	1	-	1	-	-					GRPS
Timmia norvegica	-	-	-	-	1	1	1	1	1	1	-	-	-	-	1	1	-	1	-	1	1	-	1	-	-					4
Tomenthypnum nitens	4	-	-	-	-	1	-	1	1	1	2	-	-	-	1	-	-	4	-	1	-	4	-	-	-					
Myurella julacea	1	-	1	2	1	1	1	1	-	1	1	1	-	-	1	-	1	1	1	1	-	-	1	1	-					
Aulacomnium acuminatum	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	5	-	2	-	-	-	-	-					
Bryum pseudotriquetrum	1	-	-	1	1	1	-	-	-	1	1	1	-	-	1	4	2	1	3	1	1	2	1	1	3					5
Orthothecium chryseum var. chryseum	1	-	-	-	-	-	1	-	1	-	-	-	-	-	1	-	-	4	3	1	-	-	2	1	3					
Bryum capillare	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-					
Timmia bavarica	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	-					6
Aulacomnium palustre	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	4	-	1	-					

| | | STAND GROUPS | | |

| | STAND GROUPS | | |

NON QUANTITATIVE SPECIES

75 Andreaea rupestris
76 Arctoa fulvella var. anderssonii
77 Bryum arcticum
78 Bryum argenteum
*79 Bryum creberrimum
*80 Bryum curvatum
81 Catoscopium nigritum
82 Cirriphyllum cirrosum
83 Conostomum tetragonum
84 Cratoneuron filicinum
85 Desmatodon latifolius var. muticus
*86 Desmatodon laureri
87 Funaria arctica
88 Gymnostomum recurvirostrum
89 Isopterygium pulchellum
90 Leptobryum pyriforme
91 Meesia triquetra
92 Meesia uliginosa
93 Mnium lycopodioides
94 Oncophorus virens
95 Oncophorus wahlenbergii
*96 Plagiobryum demissum
97 Pogonatum dentatum
*98 Pohlia andrewsii
** 99 Pohlia beringiensis
** 100 Pohlia filum
101 Pohlia nutans
102 Pohlia obtusifolia
103 Pohlia proligera
104 Polytrichum hyperboreum
105 Polytrichum piliferum
106 Psilopilum cavifolium
107 Schistidium gracile
108 Schistidium holmenianum
** 109 Schistidium subconfertum
110 Schistidium tenerum
111 Scorpidium turgescens
112 Stegonia latifolia var. latifolia
113 Tayloria acuminata
114 Tetraplodon mnioides
115 Tortella arctica
116 Tortella fragilis
** 117 Trichodon cylindricus

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CHAPTER III

Holocene Bryophyte Assemblages in 2 - 4 meter Slope Deposits of a High Arctic Upland, Southern Piper Pass, Northern Ellesmere Island, 82°N

by

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INTRODUCTION

The Quaternary bryophyte record in North America has been summarized and catalogued by Gams (1932), Janssens (1981, 1983), and Miller (1976, 1980a, 1980b). Bryophyte macrofossils have been analyzed from northern Ellesmere Island, N.W.T. (82°N) to Louisiana, U.S.A. (30°N). The Amblystegiaceae dominate the fossil moss record of 225 taxa, whereas the hepatic fossil record is limited to 12 taxa. Selective preservation of taxa may be due to differences in the ultrastructure of cell-walls, production of antibiotic components, and habitat preferences (Janssens 1981).

In the high arctic, limnic and terrestrial, organic deposits have been used for paleoenvironmental reconstruction (Bennike 1983; Brassard and Blake 1978; Jankovska and Bliss 1977; Fredskild 1967, 1969, 1973, 1982, 1983a, 1983b, 1985; Fredskild and Roen 1982; Fredskild *et al*. 1975; Hyvarinen 1972, 1985; Lichti-Federovich 1985; Stewart and England 1983); glacial chronology (Bjorck and Persson 1981; Blake 1972, 1974; Blake and Matthews 1979; Brown 1985; Funder 1978, 1979; Hegg 1963; Terasme *et al*. 1966; Volk 1980); and paleophytogeography (Brassard and Steere 1968, Gould 1985, King 1981; Kuc 1969, 1970, 1973a, 1973b, 1973c; Kuc and Hills 1971; Smol 1983). The reported macrofossils are predominately from allochthonous deposits in lacustrine, marine, or fluvial sediments.

Contemporary peatlands in the high arctic are confined to basin and seepage fens which is less than 5% of the landscape (Zoltai and Pollett 1974, Energy Mines and Resources 1976). Basin fens occur in areas of impeded drainage, with peat accumulation less than 50 cm. Arctic seepage fens develope on slopes with meltwater throughout the

growing season and have peat accumulations commonly 20 cm thick. Peat deposits on northern Ellesmere Island suggest accumulations are typically ice-cored mounds, 0.5 - 1.0 m thick in basin fens (England et al. 1981b). These mounds include both small palsas and high or low centered polygons (French 1976, Washburn 1982). Lag (1980,1981) has described peat formation on steep slopes, up to 42°, in Svalbard and Sondre Stromfjord,Greenland. Although these peatlands are similar to the seepage fens described by Zoltai and Pollett (1974), there are important accumulation differences.

Exceptionally thick, autochthonous peat deposits, up to four meters thick, were discovered on an upland fault block, northern Ellesmere Island in 1982. A survey of these organic sediments, rich in macrofossils, revealed undecomposed lichen thalli, bryophyte capsules, opercula and calyptrae, Dryas integrifolia plants, arctic hare coprolites, and bird bones. Because of the outstanding preservation and thickness of these peats, they were selected for paleoenvironmental analyses.

STUDY AREA

The study area is located at the southern end of Piper Pass (82°12'N, 68°31'W), northern Ellesmere Island, N.W.T. The site is on a fault block situated between the Grant Land Mountains to the north and the Hazen Plateau to the south (Fig.III.1). The fault block rises from the Hazen Plateau (457 m asl) to a major tableland (610 m asl), dissected by a ridge (915 m asl). The fault block is separated from the Grant Land Mountains by a major valley, which occurs along the Lake Hazen Fault Zone (Christie 1964). Piper Pass is a tectonic trench connecting the Hazen Plateau to Clements Markham Inlet

(Fig.III.1). The isolated fault block has no major river systems, but supports a number of seasonal streams and shallow ponds.

The fault block is a Permian sandstone tableland intruded by a diabase dike (Trettin 1971). The sandstone lithology is primarily fine to medium grained (Mial 1979). The diabase dike weathers to a coarse felsenmeer. Geologic surveying of the area has been done by Christie (1964), Mial (1978, 1979), and Trettin (1971).

The regional macroclimate for northern Ellesmere Island is defined as a polar desert (Barry and Jackson 1969). The climatic regime for the fault block has been classified as the Axel Heiberg and Ellesmere Island Highland subregion (Maxwell 1981). The study area is subject to orographic precipitation which modifies the predominant polar desert regime. Annual precipitation for the study area is estimated between the 2.5 cm/yr of Lake Hazen (155 m asl) and 13 cm/yr of Gilman Glacier (1805 m asl), for the fault block is elevationally intermediate (Corbet 1967, Jackson 1959, Hattersley-Smith 1960).

The Lake Hazen basin has been described as a "thermal oasis", based on the exceptionally warm summer temperatures recorded at the Lake Hazen Camp (Powell 1961, Corbet 1967, Jackson 1959). The southern Piper Pass fault block is located at the northeastern portion of the basin. Ameliorated summer temperatures and increased precipitation of the foothill region, enhance the potential for biotic productivity in a polar desert landscape.

The Quaternary history of northern Ellesmere Island has been extensively investigated by England (1976, 1983), England and Bradley (1978), England et al. (1981a), Bednarski (1984, 1986), Brown

(1985), and Retelle (1986). Full glacial conditions persisted until 8000 BP (Fig.III.2). The Craig Lake moraines show the position of the mountain glaciers over the Hazen Plateau during full glacial conditions (England 1983). There was an interval of slow deglaciation from 8000 - 6200 B.P. Deglaciation between 6200 - 5500 B.P. was rapid, based on the record of marine shells at the head of Chandler Fiord and the organic deposits in the foothills of the Grant Land mountains (England 1983). During full glacial conditions, Brown (1985) suggested that the Turnabout Glacier extended 16 km beyond its present margin, wrapping around the southern shoulder of the fault block (Fig.III.1). The thickness of the glacier was not sufficient to over-ride the fault block. Moraines deposited by the Divide Glacier indicate a 5 km advance beyond its present position during the same time period. Glaciers can respond differently to the same climatic regime depending upon their respective accumulation areas (Miller et al. 1975).

The objectives of the study are to: 1) quantitatively analyze four autochthonous peats for macrofossils; 2) establish the chronology and sedimentation rates by radiocarbon dating the upper, middle, and basal strata of each section; 3) relate the subfossil moss assemblages to the previously determined extant moss assemblages of the study area (LaFarge-England 1988); 4) consider paleoenvironmental implications from this fossil record; 5) compare the paleoecological data to other paleoecological studies in the high arctic.

METHODS

Ten prominent peat exposures were sampled. Four of these were

selected for detailed analyses, based on depth, stratigraphy, and preservation. The four peat deposits are located on the north-facing slope of the fault block, between 457 m and 610 m asl (Fig.III.3). This slope reaches a maximum of 40°. The lower 2/3 of the slope is patterned with ice-wedge polygons. The determination of chronology and composition of the peats provides a record of *in situ* late Quaternary vegetation in the high arctic.

The deposits (PT 1, PT 3, PT 4, and PT 2) are between 200-409 cm thick. The outer 5-10 cm of the exposed surface was removed to prevent contamination from overlying strata before sampling.

The methods of sampling were determined by the stratigraphy of the section. All samples (250 - 500 ml) were removed parallel to the bedding planes. A monolith was taken of PT 3 in 10 cm increments. For PT 1, PT 4, and PT 2, approximately 5 cm thick samples were extracted at 5 cm intervals. The thickness and interval of sampling varied according to the irregularities in the inorganic sediment.

A triplicate set of samples was collected at each horizon for analyses of macrofossils and loss on ignition; radiocarbon dating; and pollen and diatoms. Analyses on pollen and diatoms are not included in this study. Peat samples were stored in darkness at 2-3°C upon their return to the lab.

Three samples from each peat (top, middle, and base) were sent to the Saskatchewan Research Council, Radiocarbon Dating Laboratory, University of Saskatchewan, Saskatoon for ^{14}C analysis. The Saskatchewan dates were done by conventional analysis (beta counting) of large samples (>20 gr). Additional samples were submitted to Isotrace Laboratory, University of Toronto for accerator mass

spectrometry (AMS) dating. Both the Saskatchewan and Isotrace dates are corrected to a base of ^{13}C = 25 0/00 for natural, preparation, and sputtering fractionation. The AMS dates are expressed as uncalibrated radiocarbon years using the Libby ^{14}C meanlife of 8033 years and the errors are 68% confidence limits.

The macrofossils were analyzed by taking a 15-20 ml subsample, followed by wet seiving through a 0.5 mm mesh. Three mililiters of the seived portion was equally distributed in a shallow grooved tray. Each of the 5 rows was divided into four equal segments representing 5% of the total 3 ml sample and filled the field of view of a dissecting microscope at x12 (Janssens 1987). Due to the diverse range of size in the taxa, percent by volume was considered to be more accurate than concentration based on numbers of fragments (Fig.III.4). Birks and Birks (1980) have clearly stated the problem of reconstructing paleo-bryophyte assemblages based on counting fragments. Examples illustrating the size range problem in high arctic macrofossils are Aulacomnium acuminatum and Distichium spp. The percent by volume was the best method for comparison to the prominence values of the modern day assemblages (LaFarge-England 1988). Reference slides of each taxon within a peat section were made and deposited in the University of Alberta (ALTA) Cryptogamic Herbarium fossil bryophyte collection.

The macrofossil data from each peat were classified into zones by TWINSPAN, a polythetic divisive method (Hill 1979, Gauch 1982). Cut levels for the five classes were 2 5 10 20 >20, based on percent volume values. The subfossil data from each deposit were run independently, resulting in a classification of the strata into

zones. Comparisons of the subfossil assemblages and the contemporary assemblages was based upon the dominant moss species of the subfossil deposits and their occurrence within the contemporary stands analyzed on the fault block (LaFarge-England 1988).

The results of the contemporary moss assemblages indicated soil moisture content was the most important factor controlling the distribution of the moss species on the fault block (LaFarge-England 1988). A moisture preference value (MPV) was established for each of the thirteen dominant taxa of the subfossil assemblages using the soil moisture data and species prominence values from the contemporary stands (Tab.III.I). Values are expressed as:

$$MPV = \lesssim \frac{SM * PV_i}{PV_t}$$

where SM = soil moisture content for each stand; PV_i = the prominence value class of the species in each stand, and PV_t = the sum of the prominence value classes from the species in each stand for a given species i. Data used in this calculation are given in Table III.I, along with the MPV of each species. A moisture index was established by :

$$MI = \lesssim \frac{MPV_i * V_i}{V_t}$$

where MPV_i = the soil moisture preference value for a given species i; V_i = the mean percent by volume for a given species i in a given zone; V_t = the sum of mean percent by volume values for the 13 species for a given zone.

Loss on ignition was determined by drying a 20 ml subsample of peat for 16 hours at 105°C. Dry weight was recorded. The dried sample was ashed at 550°C for 16 hours. Ash weights were recorded. LOI (loss on ignition) was determined by ash wt./dry wt. times 100 as an indication of carbon content (Day et al. 1979).

RESULTS

Floristics

A total of thirty-eight taxa of mosses were determined from the macrofossil analysis. An alphabetical listing of these is included in Appendix III.I. Thirty-three species, 26 genera, and 16 families are represented. The largest number species is from the Bryaceae. The number of distinct species represents 28 % of the extant species on the fault block.

Preservation

The polar desert regime is by climatic definition constrained by moisture availability and low temperatures (Bovis and Barry 1974). Nonetheless, the shallow active layer (generally < 50 cm at this locality) restricts the depth to which the meltwater can penetrate. The active layer depth varied with the mesotopography, ranging form 10 cm to > 1 m. At some sites the active layer was saturated with meltwater during the growing season, whereas at other sites the upper active layer was dry.

On the seepage slopes, the centers of the polygons and gulleys have 100 % plant cover dominated by mosses. These sites have thin active layers and a continual supply of meltwater during the growing season. This provides optimal growing conditions for the peat forming

mosses. During the growing season, the mosses receive both nutrients and water from precipitation and meltwater derived from the active layer.

Within the annual cycle there is initial thaw, growth and refreezing. The seasonal agradation of permafrost clearly limits decomposition in the high arctic (Stutz 1977). In addition, the high arctic has low microbial activity. Most peat samples collected in temperate regions require a mixture of dilute nitric acid to be added during processing to deter fungal and algal growth on the saturated samples (Janssens 1987). This was not necessary with the peat from southern Piper Pass. The result of these pervading conditions is excellent preservation of *in situ* organics. In some samples the size of the moss fragments were limited only by the sample size.

The preservation of the macrofossils is best demonstrated by the presence of *Peltigera aphthosa* in the basal strata of PT 4 (5465 +/- 105 BP, Fig.III.12). Its presence is highly significant, because lichens are rarely found in peat deposits. Elsewhere decomposers would quickly ingest the algal and fungal components of the lichen. The preservation of lichen thalli includes the surficial cephalodia (*Nostoc* sp. algae)!

Tortula ruralis has the hyaline basal windows generally not preserved, though the hair point and papillae remain distinct. *Hylocomium splendens* has paraphyllia preserved on the stem. Tomentum is preserved on *Aulacomnium palustre*, *A. acuminatum*, and *Tomenthypnum nitens*. *Timmia norvegica* has papillae on the basal leaf sheaths, but in general the leaf laminae were poorly preserved. A capsule of *Bryum* sp. with an intact operculum and part of a seta was found. Calyptrae

of Encalypta sp. were also found several times. A hairy calyptra of Orthotrichum was found as well.

Several species of hepatics were preserved. These included Anastrophyllum cf. minutum, Tritomaria quinquedentata, T. cf. scitula, Lophozia sp.,and Cephaloziella arctica. Although hepaticae are known for their poor preservation in the fossil record (Gams 1932, Miller 1980b, Janssens 1983), their presence further demonstrates the exceptional deposition conditions within a permafrost environment.

Chlorophyll was also noted in a number of moss leaves of the subfossil material. Chlorophyll has been noted in vegetation that is being exposed by a receding glacier in Alexandra Fiord, Ellesmere Island (Bergsma et al. 1984). There Racomitrium sp. had the best chlorophyll preservation after 500 BP years, measuring 55% of its present day values.

Within the southern Piper Pass peats, Salix cf. arctica and Dryas cf. integrifolia were the two best preserved vascular species. In general the vascular plants were not preserved as well as the bryophyte macrofossils. As a consequence there are large categories of unidentifiable vascular macrofossils. Nonetheless, a whole plant of Dryas integrifolia was found intact in one of the samples. Seeds were scarce suggesting the harsh growing conditions, perhaps not making a full life cycle. The 1983 field season certainly attested to this observation, because many of the species of vascular plants did not flower. This was different than the 1980 and 1981 field seasons when flowering was largely successful on the fault block.

Unidentifiable bryophyte fragments were also found in each of the four peats, indicating strata of poor preservation and/or taxa not indentifiable. Many of the samples were identifiable to genus only (i.e. Bryum spp., Pohlia spp., Polytrichum spp.), on account of the lack of key characters.

Physiography:

Of the four peats, PT 3 and PT 4 occur on a polygonized slope, with ice-wedges up to one meter in width (Fig.III.5). The centers of the polygons are generally low centered with 100% vegetation cover. The margins of the polygons form ridges because of the thick ice-wedges. Vegetation cover averages 80% on the ridges. The centers of the polygons are saturated with seepage flow, whereas the marginal ridges are elevated above the surface water (Fig.III.6). Elsewhere, the flow of the meltwater over the patterned ground is controlled by the ice-wedges which often serve as channels between their raised rims (ridges). The remaining two peats, PT 1 and PT 2, have accumulated on slopes up to 40°. Meltwater seepage is directed by organic accumulation and horizontal fissures (Fig.III.7).

Peat Profiles

Peat 3:

PT 3 is located on the lower part of the north-facing slope (Figs.III.3,5). The peat block is continuous with polygonized ground. Marginal erosion by a gulley has exposed a four meter organic deposit, without altering the position of the peat block (Fig.III.8).

Stratigraphy

The section has stratified organics, interspersed with finely bedded sands, in an irregular pattern (Figs.III.8a,b). These strata

dip gently (7°) toward the gulley. The entire deposit is classified as a single unit, lacking major discontinuities in the stratigraphy. The contact with underlying mineral soil was not excavated due to permafrost. Clasts have been incorporated into the deposit, suggesting down-slope movement of colluvium. There was no indication of color change through the organics.

Organic Content

Organic content of the peat ranges from 2.9 - 16.0 % carbon (Fig.III.9). No trends are present. The oscillations in organic content reflect variable deposition of overland flow of sand and variable growth rates effecting accumulation rates of organics.

Chronology

A minimum date for the deposit is 6315+/-110 BP (S-2445, Tab.III.II), based on a sample collected at 400 - 409 cm. Between 205-210 cm the organics dated 5165+/-100 BP (S-2444, Tab.III.II). The uppermost sample, 7-22 cm , dated 4720+/-100 BP (S-2443, Tab.III.II). Therefore during 1600 years about 410 cm of peat and interstratified sands accumulated at this site. This gives an mean rate of deposition of 4.22 mm/yr for the upper section of the deposit (17 - 210 cm) and 1.7 mm/yr for the lower section (210 - 409 cm, Fig.III.10).

Vegetation

PT 3 has the greatest diversity of macrofossils of the four peat deposits. The bryophyte macrofossils include 35 taxa (Fig.III.9). Salix cf. arctica, Dryas cf. integrifolia, Saxifraga spp., and Carex spp.(leaf) are the principal vascular plant macrofossils. Arctic hare coprolites and lichen thalli were also visible at different horizons.

Species Patterns

The occurrence of species with depth is shown in Figure III.9. The four most important moss species within PT 3 are Tomenthypnum nitens (mesic widespread, MPV=8 moisture preference value), Bryum pseudotriquetrum (hydric-mesic widespread, MPV=12), and Philonotis fontana (hydric widespread, MPV=13) Aulacomnium palustre (hydric restricted, MPV=15). Determinations of moisture preferences of each species is based on its contemporary distribution within the sampled stands (Tab.III.I, LaFarge-England 1988).

Tomenthypnum nitens shows a minor presence in the deposit below 50 cm. From 10 - 50 cm T. nitens increases and becomes the dominant component. From 380 - 409 cm, Philonotis fontana reaches 50% of the record, whereas between 350 - 380 cm it decreases to less than 1%. Between 50 - 350 cm, Philonotis fontana fluctuates between 12% and 86%, followed by a decrease to 1% of the sample in the uppermost strata. Bryum pseudotriquetrum is present in small amounts below 150 cm reaching a maximum of 23%. There is a steady increase from 150 - 110 cm where it reaches 43%, followed by a gradual decrease to 50 - 60 cm where it is absent. There is a reappearence of B. pseudotriquetrum in the uppermost strata (20 - 50 cm) where it reaches 16 %. Aulacomnium palustre shows some prominence in the lower strata, particularly at 370 - 380 cm. It is absent in the middle strata (110 - 330 cm), and returns in the uppermost strata reaching 14% above 110 cm. Aulacomnium turgidum is present in trace amounts throughout the profile. Salix spp. macrofossils (leaves, twigs, black rootlets) are common (up to 28%) in the lower and middle strata (170 - 409 cm), then decrease to trace amounts in the uppermost strata.

Dryas cf. integrifolia is present in trace amounts throughout the strata. Vascular "unidentified material" has a fluctuating, but persistent record throughout the profile.

Zonation

From the TWINSPAN classification, five zones are delineated and the associated dendrogram is illustrated (Fig. III.9). Zone A has Tomenthypnum nitens as an indicator species. Zone B is characterized by the dominance of Philonotis fontana virtually lacking Dryas spp., Salix spp. twigs, black rootlets, and Tortula ruralis. Zone C is distinguished from B by the lack of dominance of these species. The initial division of the zones showed the following indicator species for each group: Zones A, B, C have Tomenthypnum nitens as the indicator species and Zones D and E have Salix spp. twigs and associated black rootlets and bryophyte fragments. A further division of this group by TWINSPAN analysis separates Zone E from Zone D based on the indicator species Philonotis fontana for Zone E and Salix spp. leaves for Zone D. Zone E is dominated by bryophyte fragments and vascular unidentified material.

A simpler interpretation based on the visibly dominant patterns, shows three major zones.The basal strata (350-409 cm, Zones D,E), are characterized by the dominance of bryophyte fragments and vascular unidentified material with Salix spp. macrofossils present as well. Aulacomnium palustre and Philonotis fontana are the dominant mosses of this zone. Bryum pseudotriquetrum has an abundance of less than 10%. Central strata (50 - 350 cm) are dominated by Philonotis fontana with Bryum pseudotriquetrum, vascular unidentified material, and Salix spp. macrofossils as the other major components. Small

amounts of Tomenthypnum nitens (up to 20%-30%) occur throughout this zone. These strata, are also characterized by trace amounts of numerous bryophytes (Fig.III.9). The majority of the species are classified as mesic widespread in the contemporary assemblages (LaFarge-England 1988). The uppermost strata (10 - 50 cm) are dominated by Tomenthypnum nitens, whereas Philonotis fontana decreases to less than 10%. Bryum pseudotriquetrum, Timmia austriaca, Aulacomnium palustre remain relatively the same. Barbula icmadophila, a restricted xeric species, is present in strata 40 - 50 cm (LaFarge-England 1988)

Moisture Index

Zone A has a moisture index of 8.6; Zone B - 12.2 +/-1.2, and Zone C - 11.4 +/- 0.7; Zone D - 12.9 +/- 0.3; Zone E - 10.7. A general drying trend is illustrated by the zones during the interval 6315 (6410) to 4720 BP.

Peat 4:

Pt 4 is located at the bottom of the north-facing slope, along the edge of a gulley. Erosion of colluvium beneath the peat block has caused the block to dip 29^{o} (Figs.III.11a,b). Its altered position has resulted in isolation from the slope's meltwater seepage. The bedding planes are parallel to the dip. Surface flow is directed around the block, opposed to over the block.

Stratigraphy

PT 4 is approximately two meters in depth. The basal strata consist of fine sands with organic lenses, 211 - 228 cm. The material between 162 - 211 cm is loosely compact, organic beds consisting of Salix spp. branches and bryophyte fragments. The material is dark

brown in color. 150 - 162 cm has tightly compact beds of organics, predominantly bryophyte material. These strata are red-brown in color. 135 - 150 cm are sands interbedded with thin organics, byrophytes and Salix spp. visible. Between 12 - 135 cm, the strata have loosely compact organics consisting of brown and red-brown bryophyte and Salix spp. macrofossils with finely interbedded sands. Sand lenses have a maximum thickness of 12cm.

Organic Content

The range of percent carbon is 6 - 32% (Fig.III.12). Organic content is relatively static in the lower strata averaging 7.4% +/- 1.2. There are two strata with peak values of 32% and 30% at 130 - 135 cm and 100 - 105 cm, respectively. The remaining strata have a mean value of 13.9% +/- 0.3. The upper strata show a slightly higher % organic content than the lower.

Chronology

The basal sample dated 5465 +/-105 BP (S-2448), between 203-211 cm. The sample at 100-105 cm dated 4250 +/- 95 BP (S-2447). The uppermost sample (12 - 17 cm) had a ^{14}C date of 3440 +/- 90 BP (S-2446). The 211 cm section has accumulated over 2025 years. Deposition rates of 0.84 mm/yr for 105 - 211 cm and of 1.08 mm/yr for the 12 - 105 cm are present (Fig.III.10).

Vegetation

An analysis of the macrofossils included 25 taxa of bryophytes, two vascular taxa: Dryas cf. integrifolia and Salix spp. macrofossils, and one lichen: Peltigera aphthosa.

Species Patterns

Peat 4 shows a changing pattern of vegetation throughout the

section. Philonotis fontana and Tomenthypnum nitens increase in percent volume of the strata from the bottom strata upward. Low percentages of Timmia austriaca are found throughout the section. Hylocomnium splendens is present in the peat at 182 - 188 cm and is most abundant between 110 - 155 cm. H. splendens disappears from the record above 40 cm. Aulacomnium palustre is present in the profile between 90 - 175 cm. Its abundance shows strong oscillations, though a decreasing trend is evident. A. acuminatum is restricted to the uppermost strata, between 12 - 85 cm. Orthothecium chryseum is absent from the lower strata, only evident between 50 - 55 cm. It gradually increases through the upper profile. Peltigera aphthosa is a noteworthy species dominating the basal strata.

The major moss species contributing to the peat formation are: Tomenthypnum nitens (mesic widespread, MPV=8), Philonotis fontana (hydric widespread, MPV=13), A. acuminatum (hydric-mesic widespread, MPV=11), A. palustre (hydric restricted, MPV=15), Hylocomium splendens (mesic widespread, MPV=7), and Orthothecium chryseum (hydric-mesic widespread MPV=12). The section suggests as A. palustre and H. splendens decrease, A. acuminatum and O. chryseum increase and succeed them.

Zonation

From the TWINSPAN classification four zones were delimited (Fig.III.12). The Pt 4 basal zone (Zone A: 211-182 cm) is characterized by the presence of Peltigera aphthosa, small amounts of Salix spp. macrofossils, Timmia austriaca, and Bryum spp. Zone B (175 - 90 cm) is characterized by high percentages of Hylocomium splendens, Aulacomnium palustre, Tomenthypnum nitens, and Philonotis

fontana. Trace amounts of Timmia austriaca, ≤10% Salix spp. twigs in the lower portion of the zone, and scattered occurrences of Drepanocladus uncinatus, Ditrichum flexicaule, Bryum spp., Bryum pseudotriquetrum, and Distichium spp. are also found in this zone.

Zone C (87 - 50 cm) is distinguished by the dominance of Philonotis fontana, Tomenthypnum nitens, and Aulacomnium acuminatum. Aulacomnium palustre is absent from this zone. Orthothecium chryseum is present in the uppermost sample of the zone. Hylocomium splendens decreases to less than 10%. Minor elements of the zone include Dryas sp., Encalypta alpina, Distichium spp., and Ditrichum flexicaule. There is only a trace amount of Salix spp. macrofossils. Timmia austriaca has a minor presence in this zone.

Zone D (12 - 45 cm) shows an increase in Orthothecium chryseum percent. Hylocomium splendens is present at a 1% level in 40 - 45 cm, after which it is absent. The percentages of Philonotis fontana, Tomenthypnum nitens, and Aulacomnium acuminatum remain the dominant taxa of this zone.

Moisture Index

Moisture indices for the zones are Zone A: MI=9.2, Zone B: MI=11.0, Zone C: MI=10.5, Zone D: MI=11.3 (Fig.III.12). The dominant taxa for each zone have been classified as to their moisture preference in the modern day assemblages (Tab.III.I). The basal zone is a slightly drier assemblage than the upper zones, which are relatively constant in their index values.

Peat 1:

PT 1 is the uppermost peat sampled, situated on a 40^{o} slope as a frozen block (Figs.III.13a,b). The displacement of the block is due

to erosion of underlying colluvium by the gulley. The deposit is predominantly autochthonous with a high potential of incorporating slopewash material. The strata of the deposit are parallel to the slope.

Stratigraphy

The sampled section is 223 cm in depth, though the depth of the total peat is over 300 cm. Between 153 - 279 cm the section is composed of bryophyte macrofossils and Salix spp. twigs, being dark brown in color. The organics are finely interbedded with sands and are loosely compact. From 145 - 153 there is a dense lense of bryophyte macrofossils sandwiched by sand lenses. Between 19 - 145 cm the deposit is composed of light brown to red brown bryophyte macrofossils also with finely bedded sands and loosely compact. The sand lenses are a maximum of 2 cm thick.

Organic Content

The organic content values range from 6.6 to 23.0%. The lower strata showed a relatively static organic carbon content between 133 - 223 cm, having a mean value of 12.5 +/- 3.2%. From 97 - 123 cm there is an mean organic content of 20.6 +/- 2.6%. The uppermost strata, 21 - 97 cm, show a decrease in organic content to an mean of 7.6 +/- 1.2 %. than 10% (Fig.III.14).

Chronology

The basal sample of PT 1 dated 3760 +/- 90 BP (S-2442). The depth of this sample was excavated approximately one meter below the lowermost stratum of the continuous section. The basal date of the sampled section, 218 - 223 cm, was 3450 +/- 90 BP (S-2441). The center of the section , 107 - 112 cm, dated 2995 +/- 85 BP (S-2440).

The uppermost sample, 21 - 26 cm, dated 2430 +/- 85 BP (S-2439). The rate of deposition for the lower portion of the section (223 to 112 cm) is 2.44 mm /yr. The upper portion (112 to 21 cm) has an mean rate of 1.52 mm/yr. The 223 cm of peat accumulation are recorded for 1020 radiocarbon years (Fig.III.10).

Vegetation

A total of 15 bryophyte taxa are identified. Salix spp., Saxifraga oppositifolia, and Dryas cf. integrifolia macrofossils are the three vascular taxa of the deposit. PT 1 has the least diversity of taxa of the deposits analyzed.

Species pattern

Philonotis fontana occurs sporadically within the section. It has a trace abundance in the record until 123 cm, with the exception of 187 - 192 cm having 80%. From 123 - 21 cm P. fontana has a more consistent and dominant occurrence. Abundances range from 11 - 74% with two samples having less than 1%. Aulacomnium palustre is a dominant species in the upper portion of the profile, from 133 - 21 cm. Tortula ruralis is present in the basal strata. Its pattern is virtually opposite that of Philonotis fontana, which is absent from the uppermost strata and is dominant in the strata in which it occurs. Distichium spp. is the dominant component of the basal sample. It is present in trace amounts in the central strata. The uppermost sample has 21% Distichium spp. Tomenthypnum nitens is present in one sample, 60 - 65 cm, in abundances more than trace amounts. The major peat forming mosses are Philonotis fontana, Aulacomnium palustre, Tortula ruralis, Distichium spp. and Tomenthypnum nitens. Refer to Table III.I for the moisture

preferences of the species.

Zonation

There are four major zones as a result of TWINSPAN analysis (Fig.III.14). The basal zone, Zone A: 197 - 223 cm, shows a dominance of Distichium spp. or Tortula ruralis. The remaining macrofossils are Salix spp. (cf. arctica), Dryas cf. integrifolia, Timmia austriaca, Tomenthypnum nitens, Drepanocladus uncinatus, and trace amounts of Hypnum revolutum. Zone B: 192 - 202 cm shows a distinct change in species composition with Philonotis fontana comprising 80% of the sample. Salix spp. is present along with trace quantities of Timmia austriaca, Dryas cf. integrifolia and Brachytheciaceae. In Zone A: 145 - 192 cm the strata returned to a dominance of Tortula ruralis with Salix spp. macrofossils prominent. Small amounts of Dryas integrifolia leaves were identified throughout the strata, as well as poorly preserved bryophyte stems. Trace amounts of Hypnum revolutum, Myurella julacea, and Gymnostomum recurvirostrum are present in these strata.

Zone B: 97 - 138 cm, the macrofossil data are dominated by Philonotis fontana and Aulacomnium palustre with small amounts of Distichium sp., Timmia austriaca, Tomenthypnum nitens, Drepanocladus uncinatus, Bryum pseudotriquetrum, Brachytheciaceae, and Barbula icmadophila. As well, small amounts of Salix spp. and Dryas integrifolia macrofossils are found in these strata. Zone A: 82 - 89 cm shows a change to a dominance of Tortula ruralis with Bryum spp. and Aulacomnium palustre, Bryum pseudotriquetrum, Distichium spp., and Drepanocladus uncinatus present. Salix spp. and Dryas integrifolia are also present in these strata.

Zone B: 58 - 77 cm changes in dominance to Philonotis fontana and Aulacomnium palustre with Tomenthypnum nitens being a codominant species in the uppermost strata of this zone. Distichium spp., Ditrichum flexicaule, Tortula ruralis, Drepanocladus uncinatus are present in trace amounts.

Zone C: 43 - 49 cm shows bryophyte stems, vascular unidentifeid material, and Aulacomnium palustre as the dominant taxa. Black rootlets, Tomenthypnum nitens, and Saxifraga oppositifolia comprise the remainder of the macrofossil sample, including trace amounts of Philonotis fontana and Bryum spp.

Zone D: 21 - 26, the uppermost sample shows an increase of Philonotis fontana and Bryum spp. Aulacomnium palustre decreases slightly. Distichium spp. shows a significant representation in the stratum. Salix spp. macrofossils, herbaceous material, bryphyte stems, and vascular unidentified material have remained unchanged.

Moisture Index

A moisture index for each zone is as follows ; Zone A: MI=6.3 +/-1.1; Zone B: MI=13.7 +/- 0.5; Zone C: MI=12.4; Zone D: MI=10.8. The two species controlling the moisture index for the zones are Tortula ruralis MPV=5 for Zone A, and Aulacomnium palustre MPV=15 and Philonotis fontana MPV=13 for Zone B. Zone C is dominated by Aulacomnium palustre. Zone D has Philonotis fontana, Aulacomnium palustre, and Distichium spp. MPV=5 as the dominant taxa.

Peat 2:

PT 2 is a two meter deposit, located on a 37^{o} seepage slope along an adjacent gulley on the north-facing slope (Fig.III.3). It is part of a seepage slope with no polygonal development, though

fissure wedges are evident. The surface of the peat is saturated with melt water during the growing season. The deposit is autochthonous material divided by a major sand flow (Figs.III.15a,b).

Stratigraphy

The basal portion of the exposure, 206 - 215.5 cm, is predominantly a sand layer with a few thin organic layers that are weakly stratified. Between 206 and 133 cm the deposit is composed of weakly stratified organics, which are a rich dark brown in color. Between 115 - 133 cm the section has alternating, well stratified sands and organics. The maximum thickness of the sand layers is 5 cm. The maximum thickness of the organics is 3 cm. The upper portion of the section, 155 - 22 cm, is a homogenous unit of organics with little stratification. The material is intermixed, red-brown to black-brown macrofossils. The uppermost unit, 1 - 22 cm, is composed of a rich black-brown organic layer. There is slumping at the surface with contemporary,hydric to mesic mosses and lichens growing on it.

Organic Content

The organic content of the basal strata, 212 - 147 cm, has a mean value of 10.4 +/- 3.3 %. The central section, 90 - 143 cm, has a mean % carbon of 6.9 +/- 2.3 %. The upper portion of the deposit, above 90 cm, has a mean value of 20.6 +/- 5.2 %. The upper section has a significant increase in organic content (Fig.III.16).

Chronology

The basal sample, 212.5 - 207.5 cm, dated 2880 +/-220 BP (S-2451). The middle section, 100 - 105 cm, had a radiocarbon date of 1430 +/- 85 BP (S-2450). The organics from 23 - 30 cm dated 760 +/- 75 BP (S-2449). PT 2 is the youngest deposit analyzed. The rate of

deposition in the bottom (105 - 220 cm) portion of the section is 0.78 mm /yr. The upper section (23 - 105 cm) has a rate of 1.15 mm /yr. (Fig.III.10). It has a total deposition rate of 184 cm in 2040 BP years.

Vegetation

There are 28 taxa of bryophytes, one lichen: Peltigera aphthosa, and two vascular plants: Salix spp. and Equisetum spp. (Fig.III.16).

Species patterns

The main peat forming taxa of PT 8 are Philonotis fontana, Tomenthypnum nitens, Timmia austriaca, Aulacomnium palustre, A. turgidum, Pogonatum alpinum, Pohlia spp., Bryum spp., and Bryaceae (Fig.III.16). Contemporary distributions of these taxa and their moisture preferences are in Table III.I.

Philonotis fontana comprises 21% of the basal sample. It is virtually absent from the profile between 135 - 200 cm. It is the dominant component of the upper half of the section.

Tomenthypnum nitens is restricted to the uppermost strata. Timmia austriaca has a scattered occurrence in the lower portion of the profile. From 95 cm upward, it has a continuous record in the section. Aulacomnium palustre occurs in the lower strata, below 135 cm. Bryaceae and Bryum spp. are restricted to the lower portion of the profile. Bryum spp. has a single high abundance in 110 - 115 cm of 73%.

Zonation

PT 2 is classified into four zones using TWINSPAN. The pattern of these zones are shown in Figure III.16. The development of the moss assemblages shows a progressional change through the profile, with

the basal assemblages distinct from the upper assemblages.

The basal unit, Zone A: 207.5 - 212.5 cm, is dominated by unidentified vascular material with Philonotis fontana, Aulacomnium turgidum, Pogonatum alpinum, and Pohlia spp. Zone B: 138.5 - 200 cm, is dominated by Aulacomnium palustre, A. turgidum, Pogonatum alpinum, Pohlia spp.,and Bryaceae, with small amounts of Brachytheciaceae, Bryum spp. Drepanocladus sp., Timmia austriaca and Hylocomium splendens. White rootlets (presumably from vascular plant material) are also restricted to the lower strata.

Zone C: 124 - 127 cm is dominated by Philonotis fontana with Timmia austriaca, Distichium spp., and Campylium arcticum as associated species.

Zone A is recurrent at 110 - 121 cm, here it has Bryum spp., Salix spp. black rootlets and bryophyte fragments as the dominant components. Vascular unidentified material is also a major component of these strata. From 110 - 121 cm Zone C recurrs. Philonotis fontana, Drepanocladus uncinatus, Salix spp. macrofossils are the dominant elements of the sample. Between 100 - 125 cm, the section shows an abrupt change from the basal and upper units. This central portion has a major influx of sand.

Zone D: 23 - 195 cm,is characterised by high abundances of Philonotis fontana with Tomenthypnum nitens and Timmia austriaca as the dominant species. Timmia norvegica and Drepanocladus uncinatus show scattered records in the upper strata. Hylocomium splendens and Aulacomnium palustre are restricted to the uppermost sample, 23 - 30 cm.

A moisture index for each successive zone has been calculated (Fig.III.16). Zone A: MI=10.7 (basal unit); Zone B: MI=9.5; Zone C: MI=10.2 (lowermost unit); Zone A: MI=10.0; Zone C: MI=12.5 (uppermost unit); Zone D: MI=9.9.

DISSCUSSION

Chronology

Four peat deposits from the southern Piper Pass fault block provide an overlapping organic record for the past 6400 BP years (Table III.II). Thirteen radiocarbon dates, based on both conventional and AMS techniques, provide chronological control. The dates for each peat are stratigraphically consistent, the oldest being the basal date and the youngest being the uppermost sample. The chronology of the four peats provides a continuous record from 6410 BP to 760 BP. These autochthonous deposits with the well preserved macrofossils and stratigraphy provide a unique set of data for Holocene, high arctic, paleoecology.

The AMS dating of individual plant fragments substantiates the homogeneity within the samples (>40 gr) dated by conventional beta counting. Bulk samples and individual fragments differed as little as 5 radiocarbon years, with the maximum difference being 95 years. Both comparative dates are therefore within the standard deviation of the mean values (Table III.II).

Based on both the ^{14}C chronology and the stratigraphy, the calculated mean rates of accumulation within PT 3 were most rapid between 5165 - 4720 BP, averaging 4.22 mm/yr. By comparison, the data from PT 4 show the period between 5465 - 4250 BP as having a slower rate of deposition (0.84 mm/yr, Fig.III.10). These data support the

interpretation that deposition rates are site specific and should be cautiously used for paleoclimatic interpretations. Nonetheless, the rapid sedimentation of sand or accumulation of organics indicates increasing moisture availability on these slopes.

Diversity

The total diversity of identifiable moss species from the macrofossil analysis is 28 species (Append.III.I). This represents 24% of the total moss flora of the southern Piper Pass fault block (114 species LaFarge-England 1988) and 15% of the total moss flora of northern Ellesmere Island (180 species LaFarge-England 1988). Four new taxa are reported for the North American fossil moss record (Miller 1980b, Janssens 1983): Arctoa fulvella var. andersonii, Bartramia ithyphylla, Plagiomnium medium and Psilopilum cavifolium (Append.III.I). Nearly one quarter of the contemporary moss flora is found in the four peat sections, that constitute only one slope of the fault block. Considering the variation of the contemporary stands from xeric bedrock to aquatic microhabitats, this is an excellent record from seepage fen deposits.

Trace amounts of a large number of subfossil taxa were found within the deposits (i.e. PT 3, Fig.III.9). Some of these taxa are evidence of downslope movement or aeolian debris. For example Bartramia ithyphylla grows in soil crevices which are not found in the Philonotis fontana - Aulacomnium palustre dominated seepage gulleys or inthe Philonotis fontana - Aulacomnium acuminatum dominated centers of the polygons. The allochthonous material is considered to be less than 1% of any particular sample. The species richness of the subfossil deposits show that 21/28 of the subfossil

species were present between 6410 and 4720 BP (Fig.III.9). All of the subfossil species are present in the contemporary flora of the fault block. During the initial peat accumulation on the fault block, a diverse moss flora was already established, as opposed to a gradual increase of species.

Allochthonous deposits from Clements Markham Inlet yielded 25 moss taxa from similarly aged material, 6400 +/- 60 BP (SI-4314) (Stewart and England 1983). Ten of these species are different from the southern Piper Pass macrofossil species. Therefore, a minimum of 31 species of mosses existed on northern Ellesmere between 6410 and 4720 BP. The species represent a wide range of habitats, aquatic to bedrock. The diversity by 6400 BP is noteworthy because rapid deglaciation occurred between 6000 and 4000 BP (England 1983). Between 8000 and 6000 glaciers were still within 5 - 10 km of their maximum extent during the last glaciation. Therefore the fault block peats indicate a diverse moss flora existing prior to rapid deglaciation.

Unpublished data from Disraeli Fiord and Philips Inlet on the north coast of Ellesmere Island demonstrate that bryophytes were present on Ellesmere between 33,000 BP and 7,000 BP (Lemmon 1987, Evans 1987). Isolated populations of bryophytes have therefore survived the last glaciation as evidenced by the Quaternary bryophyte flora. The diversity of the southern Piper Pass fault block peats and their similarity to present day moss assemblages illustrates the adaptability of bryophytes through glacial and non-glacial periods Bryophytes are not good indicators of macroclimatic change, but are sensitive to microclimatic variation.

Peat Forming Species

Out of the total 28 subfossil moss species the following indicates their calculated moisture preferences.

xeric widespread : 4% :1 sp.

xeric - mesic widespread : 7% : 2 spp.

xeric restricted : 4% :1 sp.

mesic widespread : 43% : 12 spp.

hydric - mesic widespread : 11% : 3 spp.

hydric restricted : 11% : 3 spp.

hydric widespread : 7% : 2 spp.

undefined : 14% :4 spp.

The predominant type of moss occurring in the peat profiles is mesic widespread (43%). The main peat forming mosses are hydric or mesic widespread opposed to those with restricted habitats (i.e. soil crevices, epilithic habitats, aquatic habitats; Tab.III.I)

The three dominant peat forming species of the deposits are Philonotis fontana, Tomenthypnum nitens, and Aulacomnium palustre. A list of other major species contributing to the peat is found in Table III.I. The combination of dominant species differs from one deposit to another. The analysis of the four peats, opposed to a single deposit, illustrated the variation of species within the subfossil assemblages, which is based on percent volume samples, as compared to quadrat samples of the contemporary stands (LaFarge-England 1988).

An analysis of each peat profile shows a different assemblage of dominating mosses:

PT 3 : Philonotis fontana/Bryum pseudotriquetrum with Tomenthypnum nitens as opposing dominant

PT 4 : Philonotis fontana /Tomenthypnum nitens/ Aulacomnium acuminatum with Hylocomium splendens and Aulacomnium palustre as opposing dominants.

PT 1 : Philonotis fontana/Aulacomnium palustre with Tortula ruralis as opposing dominant

PT 2 : Philonotis fontana/ Tomenthypnum nitens /Timmia austriaca with Aulacomnium palustre/A.turgidum /Pogonatum alpinum /Pohlia spp./Bryaceae as opposing dominants

These data show that at an individual locus a different assemblage of mosses was established, followed by different successional patterns (Figs. III. 9,12,14,16). These assemblages represent the major peat forming associations of the high arctic seepage fens. The variation of the assemblages through time reflect the dynamics of the slope processes controlling the hydrology and depositional environment of the different loci. Studies on high arctic seepage fens require numerous sample sites because of the diversity of the vegetation that typifies the seepage fen habitat.

Four of the subfossil species, Tortula ruralis, Barbula icmadophila, Bartramia ithyphylla, and Hypnum revolutum occur predominantly in xeric stands today (LaFarge-England 1988). Tortula

ruralis is the only species which contributes significantly to the peat deposits and has a widespread distribution (Tab.III.I). It is excluded from submerged or emergent stands in the contemporary flora and the bedrock habitats.

Aulacomnium palustre, Philonotis fontana, and Plagiomnium medium are the hydric species of the peat forming mosses. Philonotis fontana and Aulacomnium palustre are two of the most important peat formers in the four deposits. The remaining species have a preference for mesic stands (Tab.III.I). Three species have a mesic-hydric distribution in the contemporary flora on the fault block, Aulacomnium acuminatum, Bryum pseudotriquetrum, and Orthothecium chryseum. The four peat deposits consist of species which occur predominantly in hydric to mesic stands today.

Intra-Peat Vegetation Dynamics

Brassard and Blake (1978) described a two meter deposit, which was composed of a single species, Aplodon wormskjoldii. In contrast, the southern Piper Pass peats are composed of many species, which display a varied pattern of occurrence unique to each deposit. The deposits of of southern Piper Pass are seepage fens, opposed to basin fens predominantly analyzed deposits in other arctic studies. These are characterized by wet meadow species (i.e. Drepanocladus spp., Dicranum spp., Campylium arcticum, Calliergon spp., and Scorpidium scorpioides; (Brassard and Steere 1967, Blake and Matthews 1979, King 1981, Kuc 1970).

Studies of peat accumulation in Svalbard and Sondre Stromfjord, Greenland, showed considerable similarity to the fault block peats (Lag 1980,1981). The slope of the Svalbard peatland was 42^{o} and

included Sphagnum spp., Aulacomnium palustre, A. turgidum, and Polytrichum spp. Although there are no representatives of Sphagnum on northern Ellesmere Island today (Brassard 1971b), the Aulacomnium spp. are the same. The Svalbard peat deposits were up to 110 cm thick, rather than the commonly, cited maximum of 50 cm in arctic peats (Lag 1981, Zoltai and Pollett 1974). However these are still considerably less thick than the southern Piper Pass peats (ca. 4m).

The changes that occur within the individual peat profiles reflect microtopographic variation, rather than local, extralocal, or regional climatic variation. Slight variations in microtopography commonly produce sharp gradients between moss assemblages. For example, from the center of the polygons to the marginal ridges, their is a transition from an assemblage dominated by Philonotis fontana and Aulacomnium spp. to an assemblage dominated by Tortula ruralis and Drepanocladus uncinatus, respectively (Fig.III.6). Consequently generalizations concerning the significance of species variation through time must consider the importance of microtopography.

The following discussion will focus on intra-peat variation. The pattern of development within PT 2 reflects the major influx of sand in the middle of the profile. The lower portion of the deposit has a higher organic content (Fig. III.16), whereas the central zones (A and C) have a sharp decrease in organic content and a moss taxa indicating disturbance (i.e. poorly preserved bryophyte fragments). The upper zone (D) demonstrates the establishment of an assemblage dominated by Philonotis fontana - Tomenthypnum nitens. There is a systematic relationship between the observed organic content and the

established moss assemblages. The abrupt influx of sand resulted in a change in the moss assemblage.

The temporal record of species in PT 1 indicates an oscillation between a hydric restricted species and a xeric widespread species (Tab.III.I). The fine changes in the record may be a response to a change in the microtopography at the site and/or the change in the drainage pattern, rather than an indication of competition between the two taxa. Again these changes reflect the sharp gradients which occur on a small scale in the high arctic environment. There is no systematic relationship between the organic content and the oscillating pattern of the dominant species (Fig.III.14).

The species in PT 4 principally change from a dominance of Peltigera aphthosa to Hylocomium splendens - Aulacomnium palustre - Tomenthypnum nitens. H. splendens and A. palustre are replaced in the record by Philonotis fontana and Aulacomnium acuminatum. This succession of species indicates slight increase in the moisture regime at the site. Isolation of the peat block from the seepage slope has resulted in a drier moss assemblage at the surface. The extant moss assemblage is dominated by Hypnum revolutum, which is a xeric - mesic restricted species. No systematic relationship was evident between organic content and species patterns within PT 4.

PT 3 has Philonotis fontana established in the basal zone. In the contemporary assemblages, P. fontana has a strong relationship with high moisture values and slope. This species is the main moss taxa throughout the profile, though it has a great variation in its percentage. As its percentage decreases, Salix sp. macrofossils and unidentified vascular material increase. The detailed changes in

percentage of P. fontana through the core shows minor moisture changes at the site. The uppermost zone has Tomenthypnum nitens dominating the record. The replacement of P. fontana as the dominant taxa does indicate a drying at the site.

There are several factors to consider in the interpretation of species changes within a profile. For example, deposition of sand across a slope can be a sporadic, short-lived event, indicating only temporary saturation by overland flow. After the deposition of the sand, this porous sediment can not retain moisture unless there is continuous input. Therefore, at most sites there is no systematic relationship noted between sand lense deposition and species variations (with the exception of PT 2 which showed a distinct change in the moss assemblages). The re-establishment of a moss assemblage over a newly deposited sand lense will depend on the subsequent moisture regime of that particular site, as well as the assemblage of viable diaspores or spores.

The principal changes in species through the profiles record changes in moisture regimes and these can be related to the moisture preferences of the contemporary assemblages. However, although drying and wetting trends are noted, the variation of development within the individual peats illustrates that each site has a unique history versus uniformity. This is well illustrated by a comparison of the development of PT 3 and PT 4 which overlap chronologically. Whereas, PT 3 indicates a drying trend between 6315 and 4720 BP, PT 4 indicates a wetting trend between 5165 and 4250 BP. In conclusion, the moisture regime on the fault block during a given interval records site specific rather than regional dynamics.

The peat forming slope illustrates a number of successional patterns, opposed to the more uniform basin fen deposits. The dynamics of the physical slope processes are the controlling factors on the development of the seepage fen. These factors may or may not reflect changes in the macroclimate.

Contemporary and Subfossil Assemblages

A comparison of the contemporary and subfossil moss assemblages is based on the prominence values of taxa in the extant stands and the dominance by percent volume in the subfossil assemblages. Figure III.17a shows the DECORANA ordination of the contemporary stands. The circled stands are those which have corresponding dominant moss species as in the subfossil assemblages. Since the x-axis expresses a xeric to hydric gradient, and the y-axis is most strongly correlated with slope, the subfossil assemblages are comparable to those stands with high slope and mesic to hydric distribution (Fig.III.17a, LaFarge-England 1988).

The present day polygon centers (stand C4) are dominated by Philonotis fontana, Aulacomnium acuminatum, Tomenthypnum nitens, and Orthothecium chryseum (LaFarge-England 1988). The gulleys, on the steep slope between the peat blocks, are dominated by Aulacomnium palustre, Philonotis fontana, and Tomenthypnum nitens. The late-lying snowbank slope has 2 peat forming stands (C15b and C15c) showing Philonotis fontana dominant with Aulacomnium palustre, A. acuminatum as the 2 next most prominent moss species. C16 is an ice-wedge polygon stand and has Hylocomium splendens as the dominant species with Timmia austriaca and Pogonatum alpinum as other prominent species.

The comparison of the contemporary moss assemblages and the subfossil assemblages indicates that there has been little change over the past 6315 BP (6410) years in terms of floristic or whole assemblage change.

The establishment and growth of the ice-wedge polygons is explained by the contraction theory (French 1976). Once an ice-wedge pattern has been formed, it is unlikely to change except through ice degradation during a period of great summer warmth. Due to the similarity of contemporary moss assemblages and subfossil moss assemblages, the age of the existing communities date back to at least 6315 BP. This was also true of the peat block analyzed by Brassard and Blake (1978) dating 6280 to 4360 BP. Aplodon wormskjoldii was the sole species comprising the 2 meters of peat.

As can be seen from the surface communities of the peat blocks on the Southern Piper Pass fault block, isolation from the slopes moisture require and/or possible surface erosion by wind or other processes may have curtailed the deposition of peat at the various, marginal loci (Figs.III.11). PT 8 is the one analyzed peat which still has hydric-mesic, peat forming mosses at its surface, dominated by Philonotis fontana, Tomenthypnum nitens, and Timmia austriaca.

Paleoenvironmental Implications

The major paleoenvironmental implication of the subfossil data is that the subfossil moss assemblages are similar to the contemporary assemblages and that the subfossil species are extant on the fault block today.

In the literature, the interval of greatest postglacial warming on northern Ellesmere Island is reported to extend from 6000 to 4200 BP. This interval of ameliorated climate is supported by data from 1) driftwood penetration into the fiords (Stewart and England 1983); 2) ice shelf initiation post 3500 BP (SI-722) along the northernmost coast (Crary 1960, Lyons and Mielke 1973); 3) ^{16}O - ^{18}O changes indicating climatic ameliorations from high arctic ice cores (Dansgaard et al. 1971, Fisher and Koerner 1979, Koerner and Fisher 1981);and 4) glacial geomorphology, sea level changes and end moraines indicating the rapid retreat of glaciers after 6200 BP (England 1983).

In this study, it is noted that periods of maximum peat accumulation and sedimentation occur during this period and also suggest greater summer warmth after 6000 BP (Fig.III.10). This has also been suggested by Blake (1972) and Brassard and Blake (1978) on a regional scale for the Queen Elizabeth Islands. From the species pattern data, there is no clear indication of this warming. The macrofossil moss data on the southern Piper Pass fault block does not indicate that there have been uniformly recognisable climatic changes during the past 6400 BP years. This contrasts with the conclusions drawn from other paleoenvironmental studies in this region during the same interval based on pollen, diatom, and moss records (Brassard and Blake 1978, Fredskild 1985, Smol 1983).

The detailed study of these peats (<6400 BP) demonstrates the considerable floristic diversity during the early part of the deglacial cycle on northern Ellesmere Island and it shows the resilient nature of bryophytes to persist in microhabitats when other

Figure III.1 Locality map of study area on the fault block at the southern end of Piper Pass. Southern Piper Pass (diamond) at the northern portion of the map is shown in the inset. Number of moss species known for each locality is shown.

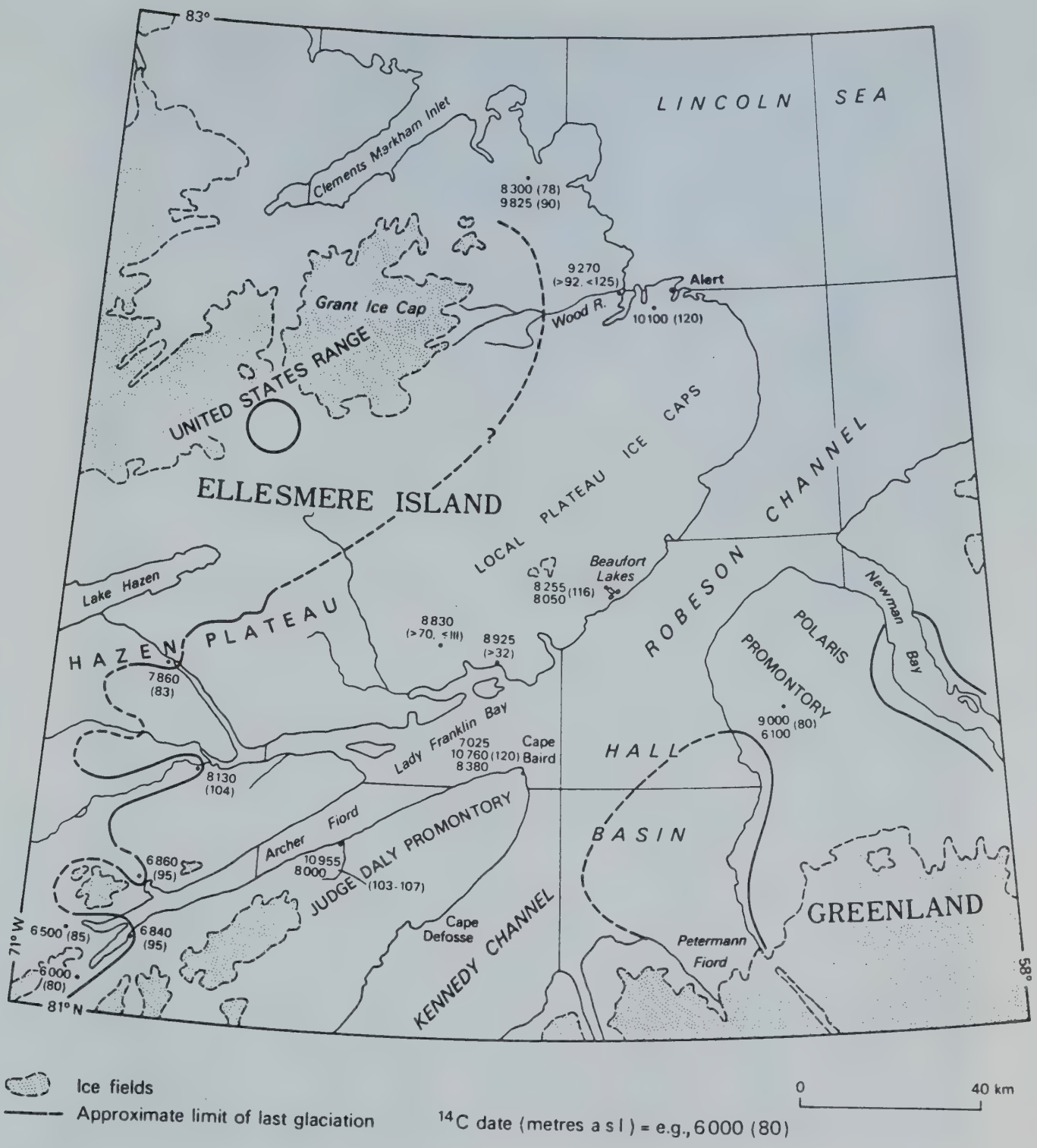


Figure III.2 The advance of glaciers from the United States range over the Hazen Plateau during the last glaciation is shown by the dotted line. The study area is indicated by the circle. (Modified from England 1983).

Figure III.3 A vertical air photo showing the localities of the peat deposits (1,2,3,4) sampled. The arrow indicates north.

Figure III.4 A photo showing the diversity in size of the macrofossils encountered in the quantitative analysis. List of species:front row left to right: Salix arctica (leaf), Philonotis fontana, Pogonatum alpinum, Aulacomnium turgidum, Dryas integrifolia, Aulacomnium acuminatum, Salix arctica (twig), Hylocomium splendens; back row from left to right: Tomenthypnum nitens, Timmia austriaca, and Aulacomnium palustre.

Figure III.5 A view of the polygonized peat forming slope. Exposed peat sections (PT1, PT3, PT4) occur along the margin of the gulley. The main drainage valley in the center of the photo empties into a proglacial lake at the southern end of Piper Pass.

Figure III.6 A photo of the polygon pattern on the peat forming slope. The centers of the polygons show moss dominated assemblages. The ridges at the margins of the polygons are dominated by vascular plants. The ice wedges channel the surface flow and cause the ridge formation. Major species changes are evident in the various microhabitats.

Figure III.7 Horizontal fissures were evident on the peat forming slope. The fissures control the surface flow, resulting in a different moss assemblage above and below the fissure.

8a

8b

Figure III.8a) A photo of the PT 3 section, illustrating over 4 meters of sedimentation and growth. The deposit is still contiguous with the polygonized slope. This section represents an autochthonous deposit dating from 6315 (6410) to 4720 BP. 8b) A detailed photo of PT 3 showing the near horizontal strata. The clast in the upper strata is evidence of down slope movement of colluvium.

Figure III.9 A macrofossil diagram of PT 3. Depth in centimeters is indicated by Depth in cm; C^{14} is radiocarbon dates in years BP; %LOI refers to percent organic content of the individual peat strata; All taxa are presented - Encalyp./Desmat./Tort. refers to Encalypta, Desmatodon, or Tortula taxa; TWINSPAN ZONES are indicated by A - D; MI refers to the moisture indicies for each zone; quantification was by % volume = percent by volume. (In jacket at back of thesis)

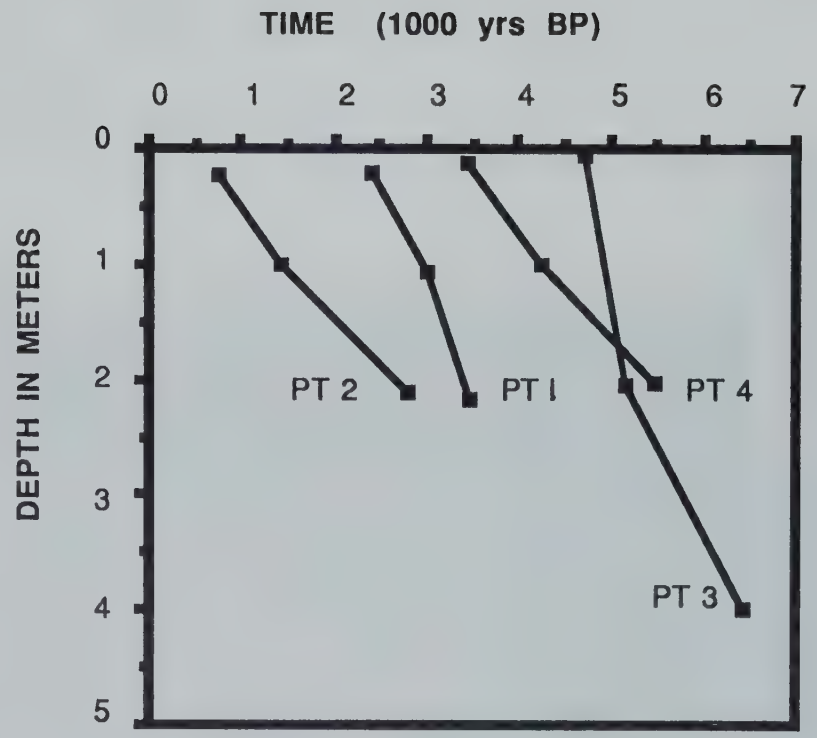
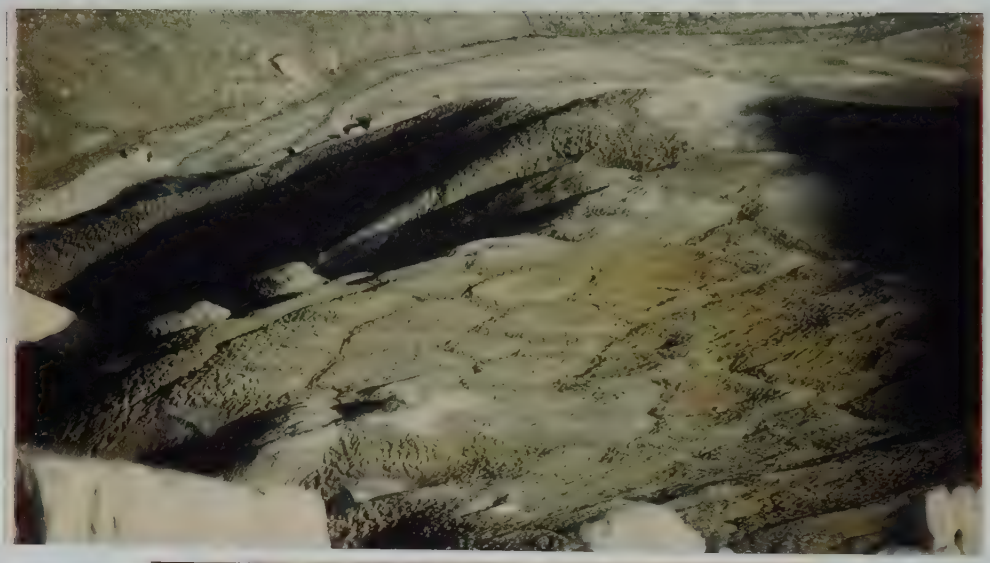


Figure III.10 Rate of deposition for each of the four deposits. Peat 3 shows the most rapid growth and sedimentation between 5165 and 4720 BP years of 4.2 cm/yr.

11a



11b

Figure III.11a) A photo of PT 4 located at the bottom of the peat forming slope. Erosion by the gulley has caused the peat block to dip downslope. The age of the deposit ranges from 5460 at the base to 3440 near the surface. Isolation from the slope's moisture source is presumed as the main cause for the cessation of peat formation. 11b) A detailed photo of the section showing parallel strata at a 29^{o} dip.

Figure III.12 Macrofossil diagram of PT 4. Depth in centimeters is indicated by Depth in cm; C^{14} is radiocarbon dates in years BP; %LOI refers to percent organic content of the individual peat strata; All taxa are presented - Encalyp./Desmat./Tort. refers to Encalypta, Desmatodon, or Tortula taxa; TWINSPAN ZONES are indicated by A - D; MI refers to the moisture indicies for each zone; quantification was by % volume = percent by volume (In jacket at back of thesis).

13a

13b

Figure III.13a) A photo of PT 1 showing the altered position of the frozen block on the upper slope. A person for scale is seen on the surface of the deposit. 13b) A photo of PT 1 resting on a 40° slope. A 223 cm section was sampled for analysis, though the section's maximum thickness was estimated to be a minimum of 3.5 m thick.

Figure III.14 A macrofossil diagram of PT 1. Depth in centimeters is indicated by Depth in cm; C^{14} is radiocarbon dates in years BP; %LOI refers to percent organic content of the individual peat strata; All taxa are presented; TWINSPAN ZONES are indicated by A - D; MI refers to the moisture indicies for each zone; quantification was by % volume = percent by volume (In jacket at back of thesis).

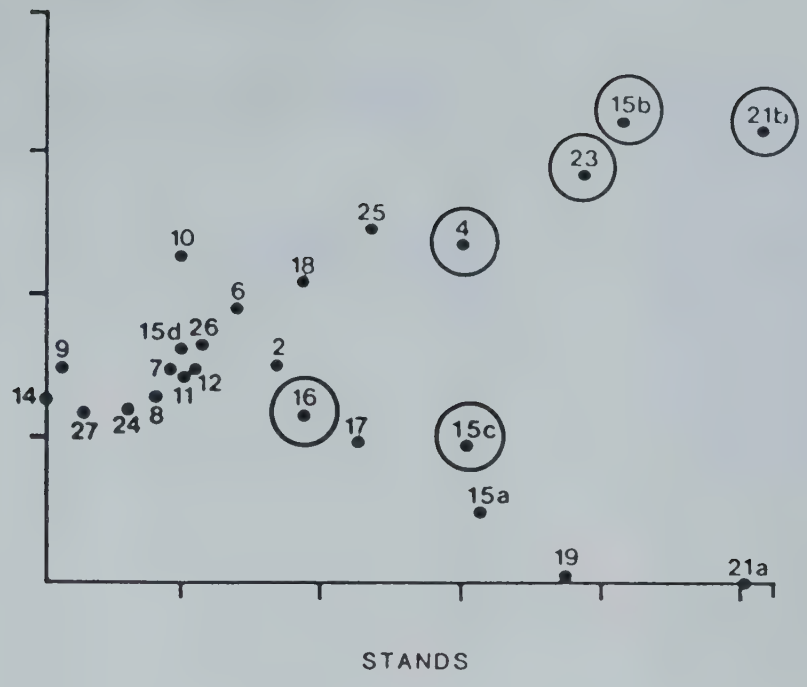
15a

15b

Figure III. 15a A general view of PT 2 showing its continuity with the seepage slope. Presentday moss assemblages at the deposits surface are hydirc-mesic species. 15b A detailed photo of the section showing the major deposition of sand in the central portion of the profile. The upper and basal portions of the section are composed of different dominant bryophytes.

Figure III.16 A macrofossil diagram of PT 2. Depth in centimeters is indicated by Depth in cm; C^{14} is radiocarbon dates in years BP; %LOI refers to percent organic content of the individual peat strata; All taxa are presented; TWINSPAN ZONES are indicated by A - D; MI refers to the moisture indicies for each zone; quantification was by % volume = percent by volume (In jacket at back of thesis).

17a



17b

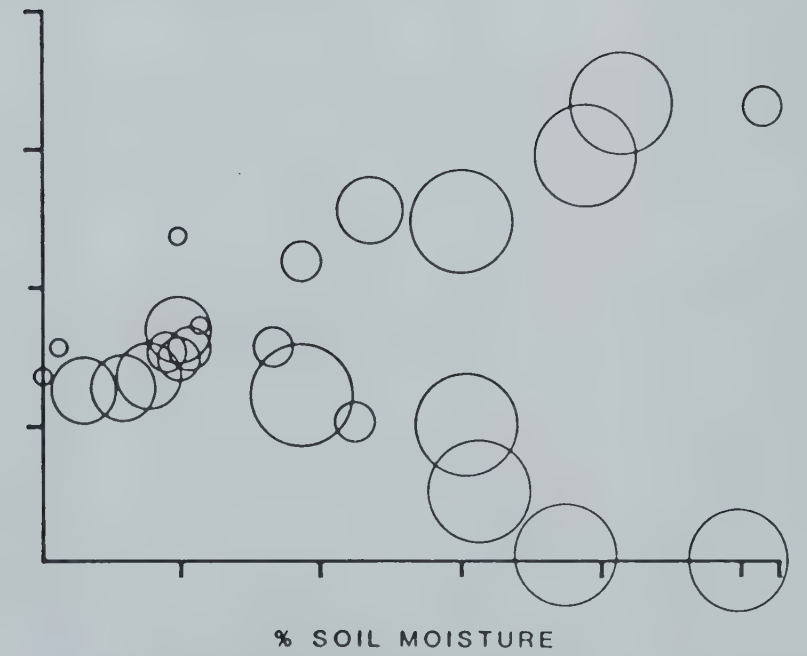


Figure III. 17a The DECORANA ordination of the two main axes of the contemporary vegetation data (from LaFarge-England 1988). 17b The contemporary stands with percent soil moisture values superimposed over the DECORANA ordination of the stands. The circled stands are those which most closely represent the subfossil assemblages

species	STD GRP 1							STD GRP 2								STD GRP 3					STD GRP 4			STD GRP 5			MPV	CONTEMPORARY MOISTURE PREFERENCES
	18	10	6	12	15d	25	26	7	8	11	24	27	9	14	2	15c	16	4	17	15b	21b	23	15a	19	21a		
Tort.rur.	2		1	3	2	1	1	3	3	3	5	5	4	4	2	2	4		1	1	1	1				5	x w
Barb.icm.		1	1	1		1	1	1	1	1			1		1			1								4	x r
Dist.cap.	1	1	2	3	1	3	2	1	1	2	1	1	1		2		1	3	3	1	1		1			5	m w
Timm.aus.	1		2	1	1	1	1	2	1	2	1	1			4	1	4	3	4	1	1	1	1	1		6	m w
Pogo.alp.	1			2	1	1	1	1		1	2				3	3	3	1	2	1			1	2		6	m w
Tome.nit.	4					1		1	1	1	2				1			4		1		4			3	8	m w
Bryu.pse.	1			1	1	1				1					1	4	2	1	3	1	1	2	1	1	3	12	h-m w
Orth.chr.	1						1		1						1		1	4	3	1	5		2	1	2	12	h-m w
Phil.fon.						2		1		1					1	3	1	4	1	5	5	5	1	1		13	h-w
Hylo.spl.	1								1	1			1		1		4	3	1					1		7	m w
Aula.tur.	2										1						2			1				1		9	m w
Aula.acu.	1							1										5		2						11	h-m w
Aula.pal.						1														2		4		1		15	h r

Table III.I The dominant subfossil moss species showing their distribution in contemporary stands (LaFarge-England 1988). STD GRP refers to the stand group as delineated by TWINSPAN classification from the contempoary data set. The row of numbers below the stand groups are the individual stands within each stand group. MPV refers to the moisture preference value assigned to each species as calculated from the soil moisture and prominence values for each species. Moisture preferences are assigned to each species based on its distribution through the contemporary stands (LaFarge-England 1988).

sample #	depth in cm	c14 dates	laboratory #
PT 2	23 - 30	760 +/- 75	S-2449
PT 2	100 - 105	1430 +/- 85	S-2450
PT 2	207 - 220	2800 +/- 220	S-2451
PT 1	21 - 26	2430 +/- 85	S-2439
PT 1	107 - 112	2995 +/- 85	S-2440
PT 1	218 - 223	3450 +/- 90	S-2441
PT 1	est. 323	3760 +/- 90	S-2442
PT 4	12 - 17	3440 +/- 90	S-2446
PT 4	100 - 105	4250 +/- 95	S-2447
PT 4	203 - 211	5465 +/- 105	S-2448
" "	" "	5460 +/- 80	TO-283
PT 3	17 - 22	4720 +/- 100	S-2443
PT 3	205 - 210	5165 +/- 100	S-2444
PT 3	400 - 409	6315 +/- 110	S-2445
" "	" "	6410 +/- 50	TO-284

Table III.II Radiocarbon dates of the southern Piper Pass peats, northern Ellesmere Island, N.W.T.: 82° 12′ N, 68° 31′W. S refers to dates from the Saskatchewan Research Council, Radiocarbon Laboratory; TO refers to Isotrace Laboratory, University of Toronto.

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CHAPTER IV

SUMMARY OF
THE CONTEMPORAY AND SUBFOSSIL
MOSS ASSEMBLAGES OF A HIGH ARCTIC UPLAND,
NORTHERN ELLESMERE ISLAND, CANADA

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SUMMARY

The research on the contemporary and subfossil moss assemblages on a fault block at the southern end of Piper Pass, northern Ellesmere Island, N.W.T. has contributed a set of local data to the Holocene paleoenvironment. The initial portion of the research established a quantified data base of the contemporary moss assemblages. The vegetation data was then ordinated by DECORANA, a detrended correspondence program. TWINSPAN, a two way indicator species analysis program, classified the vegetation data into 5 major stand groups and 7 major species groups. A set of physical parameters including % moisture, slope, soil pH, cations analysis of the soil, water pH and conductivity, % organic content of the soil, CEC (total cation exchange capacity), and soil texture. These parameters were then correlated with the distribution of the sampled stands of vegetation by the DECORANA ordination. The results of the vegetation and physical parameter data showed that % soil moisture and slope were the two most important factors controlling the distribution of the 28 sampled stands. The distributions of the individual species through the stands and stand groups was used to interpret the subfossil moss assemblages.

A selection of four autochthonous peats ranging from 2 - 4 meters thick was made for the analysis of paleoenvironments. Quantification of the macrofossils was made by % volume, due to the size range of the taxa. The results of the subfossil analysis showed that the peats have been stratigrapically preserved as in situ material despite dipping of the frozen blocks by erosion of underlying sediments. The permafrost environment as been a key factor in the excellent preservation of the macrofossils. The outstanding record is clearly Peltigera aphthosa, a

thalloid lichen which as cephalodia preserved on its surface. This is unheard of at more southerly latitudes.

The chronology of the four deposits, spans 6315 BP (S-2445) radiocarbon years. Dating individual fragments gave a maximum age of 6410 BP (TO-284), using accelerator mass spectrometer techniques. The diversity of the subfossil moss taxa show 28 species of mosses present between 6315 and 4720 BP. This represents about one quarter of the contemporary moss flora on the fault block. The subfossil species are all present in the contemporary moss flora. A comparison of the contemporary to the subfossil assemblages show there are modern day analogues. The analysis of the four peats showed that there was variation in the dominant species pairs from one peat to another. The main peat forming moss species are Philonotis fontana, Tomenthypnum nitens, Aulacomnium spp., Hylocomium splendens, and Tortula ruralis. Analysing four gave a broader perspective of the possible subfossil moss assemblages. The sample size of the macrofossil must be kept in mind when interpreting the data,(3 ml). This is opposed to the 25 cm^2 quadrat sample size of the contemporary stands.

The subfossil assemblages did not change radically in species composition throughout the record. This is a significant finding, since previous paleoenvironmental data show periods of cooling and warming in the last 6000 BP years (Brassard and Blake 1978, Smol 1983, Koerner and Fisher 1981, Stewart and England 1983, Fredskild 1985, Hyvarinen 1985, and Bennike 1983). The variations in the species assemblages within the peats may strictly be due to microhabitat conditions opposed to regional climatic change. Though, there is a correlation between the fastest rate of deposition, 5165 (S-2444) - 4720 (S-2443) BP,

and the greatest driftwood abundance on the nort coast, 6000 - 4200 BP (Stewart and England 1983). Conflicting data from another peat shows the second slowest rate of deposition during the same interval, 5465 (S-2448) to 4250 (S-2447) BP.

The typical peat development in the high arctic averages 50 cm (Zoltai and Pollett 1974). The discovery of the four meter deposit was exceptional and its situation on sloping terrain, rather than the more common basin fen of the well known wet meadow ecosystems of the high arctic (Vitt and Pakarinen 1977).

The present study is one of the first detailed accounts of both contemporary and subfossil moss assemblages in the high arctic. Its contribution is in understanding the local paleoenvironment during the Holocene.

One of the original objectives was to demonstrate the hypothesized refugia for northern Ellesmere Island. The exceptional thickness of peat was presumed to predate the maximum extent of the last ice margin (England and Bradley 1978, England 1983). The conclusion of the study is that the peats record the post glacial environment, for the last 6400 BP years. The Holocene moss record shows similar moss assemblages to what exists today.

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APPENDIX I

SUBFOSSIL MOSSES OF SOUTHERN PIPER PASS

NORTHERN ELLESMERE ISLAND, N.W.T.

Arctoa fulvella (Dicks.) B.S.G. var. andersonii (Wich.)Grout

Aulacomnium acuminatum (Lindb. & Arnell) Kindb.

A. palustre (Hedw.) Schwaegr.

A. turgidum (Wahlenb.) Schaegr.

Barbula icmadophila Schimp. ex C. Muell.

Bartramia ithyphylla Brid.

Brachythecium sp.

Bryum cryophilum Mart.

B. pseudotriquetrum (Hedw.) Gaertn., Meyer & Scherb.

Bryum sp.

Bryaceae

Campylium arcticum (Williams) Broth.

Campylium sp.

Didymodon sp.

Distichium capillaceum (Hedw.) B.S.G.

Distichium sp.

Ditrichum flexicaule (Schwaegr.) Hampe

Drepanocladus uncinatus (Hedw.) Warnst.

Encalypta alpina Sm.

Gymnostomum recurvirostrum Hedw.

Hylocomium splendens (Hedw.) B.S.G.

Hypnum revolutum (Mitt.) Lindb.

Myurella julacea (Schwaegr.) B.S.G.

Orthothecium chryseum (Schwaegr. ex Schultes) B.S.G.

Philonotis fontana var. pumila (Turn.) Brid.

Plagiomnium medium (B.S.G.) Kop.

Pogonatum alpinum (Hedw.) Roehl.

Pohlia nutans (Hedw.) Lindb.

Polytrichum juniperinum Hedw.

Psilopilum cavifolium (Wils.) Hag.

Psilopilum sp.

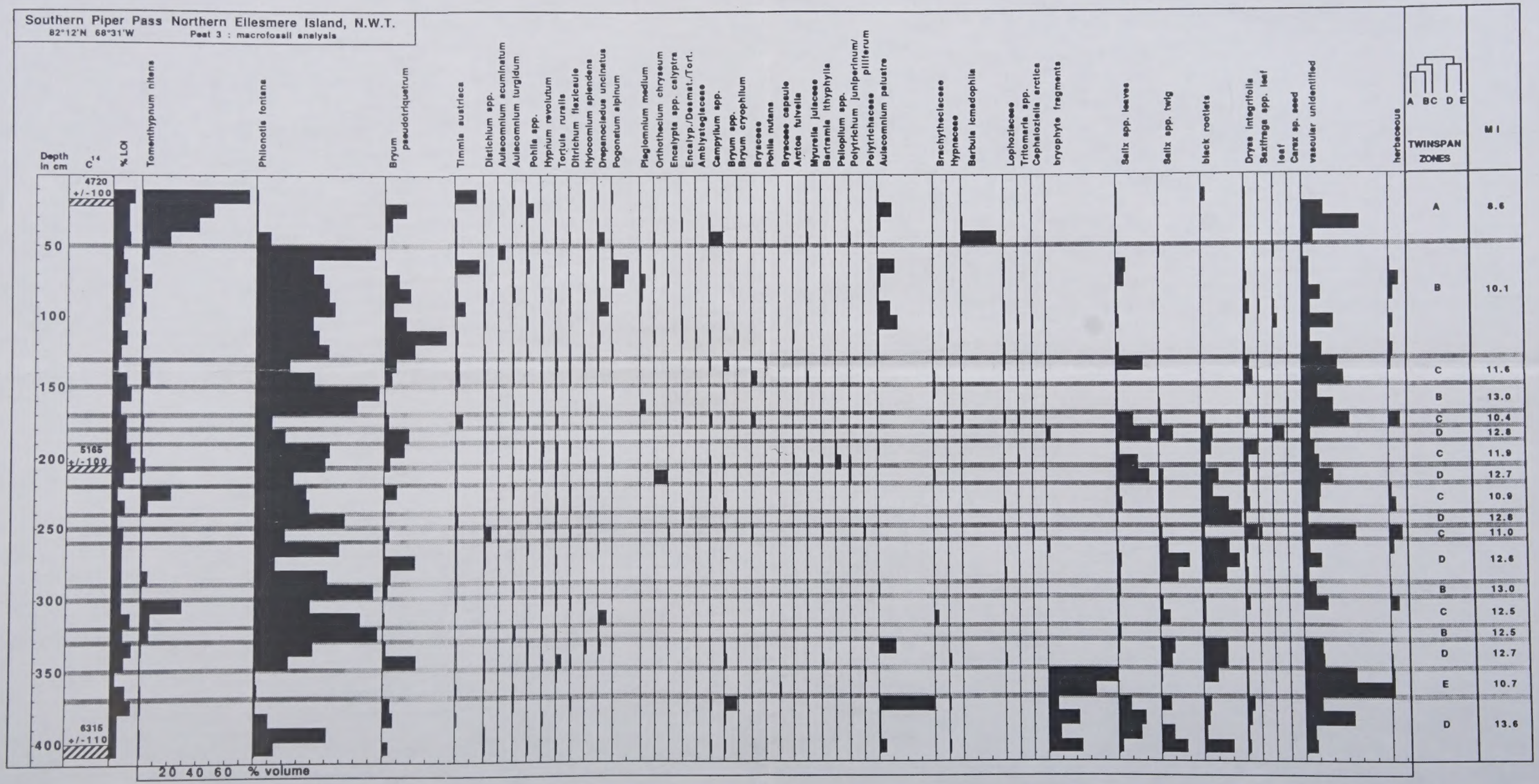
Timmia austriaca Hedw.

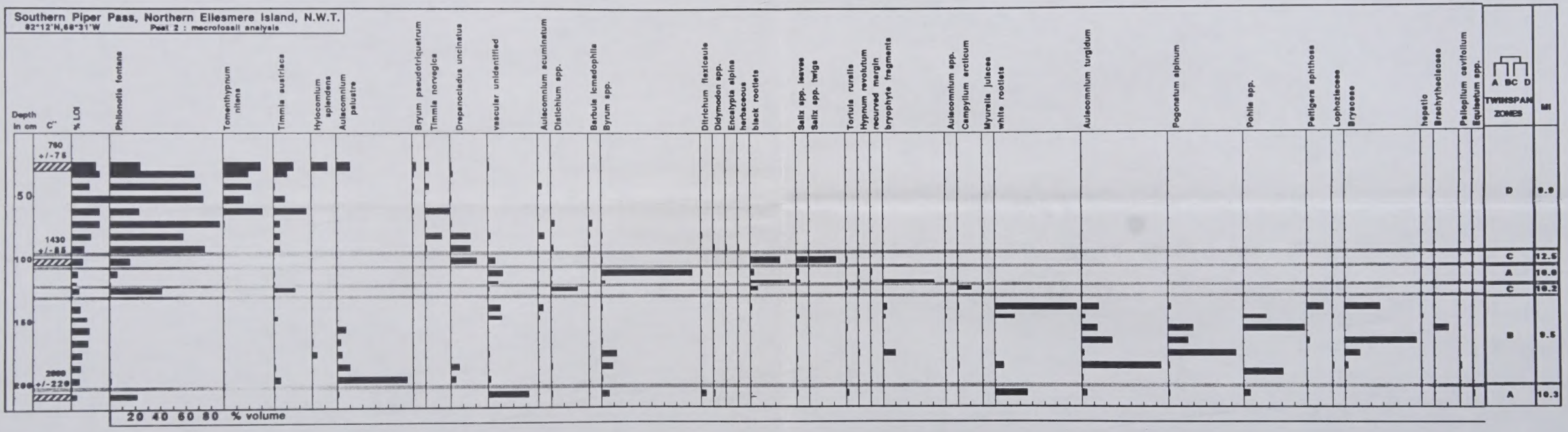
T. norvegica Zett.

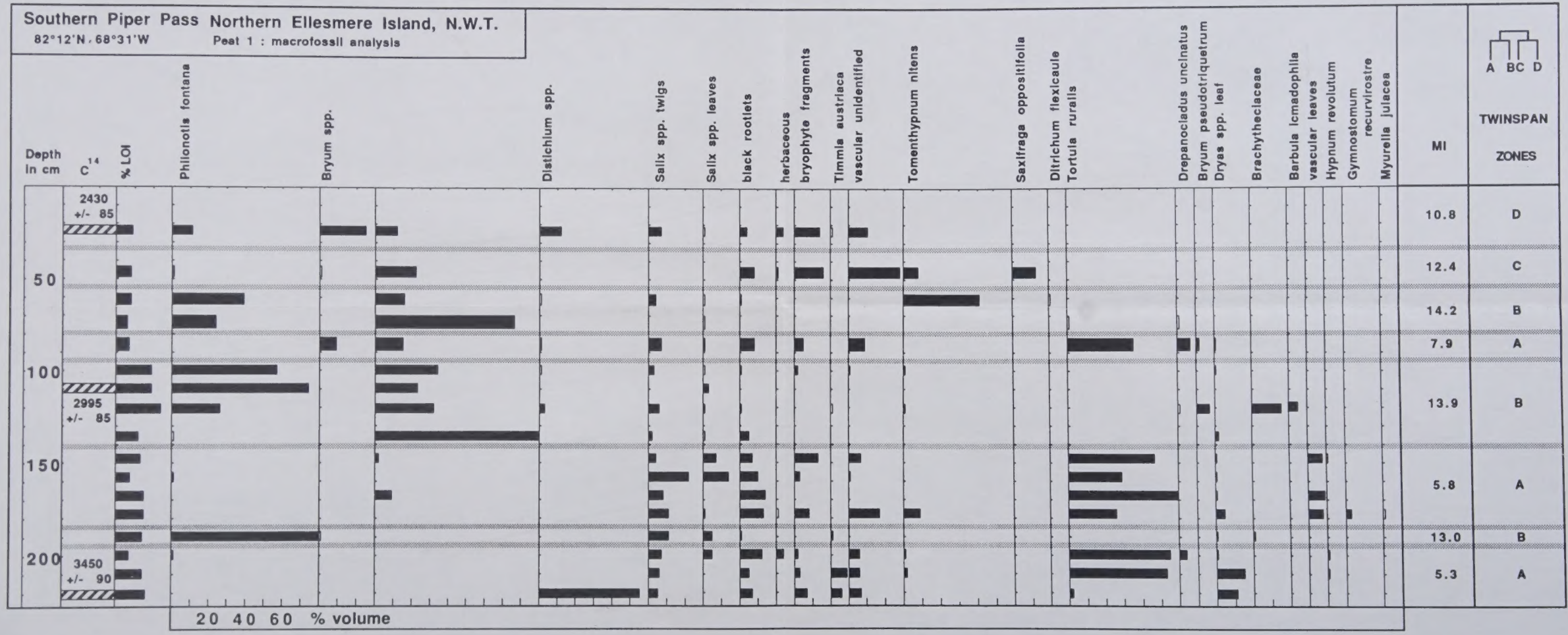
Tomenthypnum nitens (Hedw.) Loeske

Tortula ruralis (Hedw.) Gaertn., Meyer & Scherb.

Southern Piper Pass, Northern Ellesmere Island,N.W.T.
82°12'N,68°31'W
Peat 4 : macrofossil analysis
% LOI
C14
Depth in cm
3440 +/-90
4250 +/95
5465 +/105
Philonotis fontana
Tomenthypnum nitens
Aulacomnium acuminatum
Orthothecium chryseum
Timmia spp.
Hypnum revolutum
Didymodon spp.
Cephaloziella arctica
Timmia norvegica
Dryas sp. leaves
Encalypta alpina
Pogonatum alpinum
Tortula ruralis
Lophoziaceae
Timmia austriaca
Hylocomium splendens
Aulacomnium palustre
Distichium spp.
Ditrichum flexicaule
Bryum pseudotriquetrum
Bryum spp.
Drepanocladus uncinatus
Pohlia spp.
bryophyte fragments
debris
Tritomaria spp.
Bryaceae
Brachythecieceae
Peltigera aphthosa
black rootlets
Aulacomnium turgidum
vascular
Salix spp. twigs
Salix spp. leaf
TWINSPAN ZONES
A B C D
MI
11.3
10.5
11.0
9.2
% volume


Southern Piper Pass Northern Ellesmere Island, N.W.T.
82°12'N 68°31'W
Peat 3 : macrofossil analysis
Depth in cm
C14
% LOI
Tomenthypnum nitens
Philonotis fontana
Bryum pseudotriquetrum
Timmia austriaca
Distichium spp.
Aulacomnium acuminatum
Aulacomnium turgidum
Pohlia spp.
Hypnum revolutum
Tortula ruralis
Ditrichum flexicaule
Hylocomium splendens
Drepanocladus uncinatus
Pogonatum alpinum
Pleglomnium medium
Orthothecium chrysseum
Encalypta spp. calyptra
Encalyp./Desmat./Tort.
Amblystegiaceae
Campylium spp.
Bryum spp.
Bryum cryophilum
Bryaceae
Pohlia nutans
Bryaceae capsule
Arctoa fulvella
Myurella julacea
Bartramia ithyphylla
Pellopilum spp.
Polytrichum juniperinum/ piliferum
Polytrichaceae
Aulacomnium palustre
Brachytheciaceae
Hypnaceae
Barbula icmadophila
Lophoziaceae
Tritomaria spp.
Cephaloziella arctica
bryophyte fragments
Salix spp. leaves
Salix spp. twig
black rootlets
Dryas integrifolia
Saxifraga spp. leaf
leaf
Carex sp. seed
vascular unidentified
herbaceous
A BC D E
TWINSPAN ZONES
MI
4720 +/-100
5165 +/-100
6315 +/-110
50
100
150
200
250
300
350
400
20 40 60 % volume
A 8.6
B 10.1
C 11.6
B 13.0
C 10.4
D 12.8
C 11.9
D 12.7
C 10.9
D 12.8
C 11.0
D 12.6
B 13.0
C 12.5
B 12.5
D 12.7
E 10.7
D 13.6


Southern Piper Pass, Northern Ellesmere Island, N.W.T.
82°12'N,68°31'W
Peat 2 : macrofossil analysis
Depth in cm
C''
% LOI
760 +/-75
1430 +/-85
2000 +/-220
Philonotis fontana
Tomenthypnum nitens
Timmia austriaca
Hylocomium splendens
Aulacomnium palustre
Bryum pseudotriquetrum
Timmia norvegica
Drepanocladus uncinatus
vascular unidentified
Aulacomnium acuminatum
Distichium spp.
Barbula hmadophila
Byrum spp.
Ditrichum flexicaule
Didymodon spp.
Encalypta alpina
herbaceous
black rootlets
Salix spp. leaves
Salix spp. twigs
Tortula ruralis
Hypnum revolutum
recurved margin
bryophyte fragments
Aulacomnium spp.
Campylium arcticum
Myurella julacea
white rootlets
Aulacomnium turgidum
Pogonatum alpinum
Pohlia spp.
Peltigera aphthosa
Lophoziaceae
Bryaceae
hepatic
Brachytheciaceae
Pellopilium cavifolium
Equisetum spp.
20 40 60 80 % volume
A BC D
TWINSPAN ZONES
MI
D 9.9
C 12.5
A 10.0
C 10.2
B 9.5
A 10.3


Southern Piper Pass Northern Ellesmere Island, N.W.T.
82°12'N, 68°31'W
Peat 1 : macrofossil analysis
Depth in cm
C14
% LOI
Philonotis fontana
Bryum spp.
Distichium spp.
Salix spp. twigs
Salix spp. leaves
black rootlets
herbaceous
bryophyte fragments
Timmia austriaca
vascular unidentified
Tomenthypnum nitens
Saxifraga oppositifolia
Ditrichum flexicaule
Tortula ruralis
Drepanocladus uncinatus
Bryum pseudotriquetrum
Dryas spp. leaf
Brachytheciaceae
Barbula icmadophila
vascular leaves
Hypnum revolutum
Gymnostomum recurvirostre
Myurella julacea
MI
TWINSPAN ZONES
A BC D
2430 +/- 85
2995 +/- 85
3450 +/- 90
50
100
150
200
10.8
12.4
14.2
7.9
13.9
5.8
13.0
5.3
D
C
B
A
B
A
B
A
20 40 60 % volume

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